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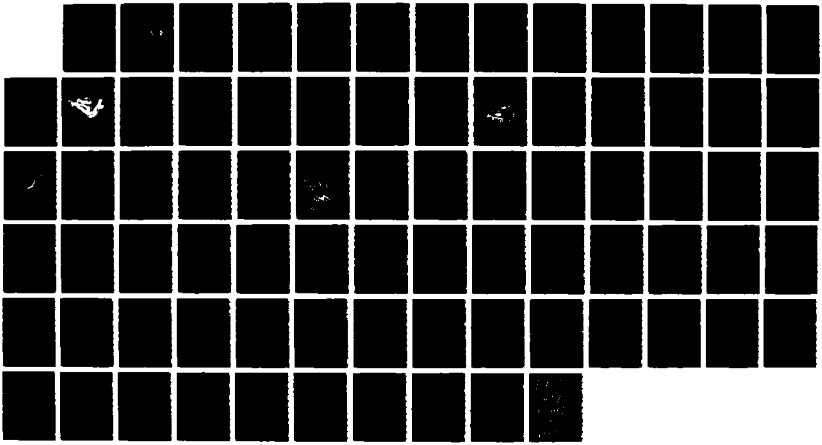

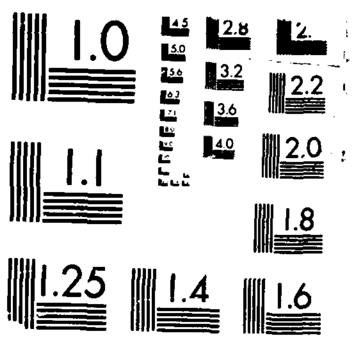

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April 1988
Application of Solid Fuels by Direct Combustion

US Army Corps of Engineers
Construction Engineering Research Laboratory

AD-A194 537

Characteristics of Incinerators With Heat Recovery Capability

by
K. Griggs
G. Chamberlin
R. Ducey
G. Schanche

A wide range of equipment is available for incinerating wastes and recovering the heat released as useful energy. These heat recovery incinerators (HRIs) can be grouped into four categories: starved-air modular, rotary kiln, excess-air grate, and fluidized bed combustion. State-of-the-art HRI technology has been reviewed to update the military knowledge base. Findings represent data collected from approximately 30 manufacturers of this equipment through literature review, direct survey work, and information exchange with other facilities investigating this area. The different technologies and products available are compared and evaluated for potential application at military installations.

Information in this report will help potential military HRI users in making a preliminary assessment of the technologies and manufacturers capable of satisfying their needs. Those which are judged acceptable can then be subjected to a detailed assessment to quantify the functionality and cost-effectiveness of their application to a particular project.

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A wide range of equipment is available for incinerating wastes and recovering the heat released as useful energy. These heat recovery incinerators (HRIs) can be grouped into four categories: starved-air modular, rotary kiln, excess-air grate, and fluidized bed combustion. State-of-the-art HRI technology has been reviewed to update the military knowledge base. Findings represent data collected from approximately 30 manufacturers of this equipment through literature review, direct survey work, and information exchange with other facilities investigating this area. The different technologies and products available are compared and evaluated for potential application at military installations.

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Information in this report will help potential military HRI users in making a preliminary assessment of the technologies and manufacturers capable of satisfying their needs. Those which are judged acceptable can then be subjected to a detailed assessment to quantify the functionality and cost-effectiveness of their application to a particular project.

FOREWORD

This study was performed by the Energy Systems Division (ES), U.S. Army Construction Engineering Research Laboratory (USA-CERL), for the U.S. Army Engineering and Housing Support Center (USAEHSC). The work was completed under Project 4A762781AT45, "Energy and Energy Conservation;" Task D, "Solid Fuels Application Strategy;" Work Unit 007, "Application of Solid Fuels by Direct Combustion." Mr. B. Wasserman, CEHSC-FU, was the USAEHSC Technical Monitor.

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1 INTRODUCTION

Background

The Resource Conservation and Recovery Act of 1976 recommended the use of recovered material derived fuels to the maximum extent practical in Federally owned fossil-fuel-fired energy systems. To fulfill the intent of the act and to take advantage of possible energy cost savings, the Army has installed heat recovery incinerators (HRIs) at various military facilities throughout the continental United States (CONUS). The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has published several reports containing planning information for such facilities.[1]

In addition to the above mandate, the existing sites for solid waste disposal are nearing the end of their useful lives in many parts of the country. The problem is especially acute in the eastern half of CONUS where most Army bases are located. It is becoming extremely difficult and very expensive to open new landfills due to more stringent regulations. The Army is facing the same difficulties as the rest of the nation in complying with Federal, State, and local environmental legislation governing new landfill sites. In addition to these obstacles, commercial (private sector) site developers must deal with public opposition to disposal techniques and location.

Onsite incineration provides a mechanism to increase the expected life of a landfill by reducing waste volume up to 90 percent. This technology can extend a 2-year landfill's life expectancy up to 20 years. Furthermore, coupling an incinerator to a heat recovery boiler produces the added benefit of generating usable energy. At present, HRIs are operational at Forts Eustis, VA, Leonard Wood, MO, Rucker, AL, and Dix, NJ, and at Redstone Arsenal.

Unlike other fossil-fueled equipment, such as coal- or oil-fired boilers, there has been too little quality experience with burning wastes to establish clear guidelines as to which technology is most appropriate for a given situation. Moreover, many manufacturers are still establishing their products and reputations. Installation Directorates of Engineering and Housing (DEHs) and District Engineers (DEs) need information about the various HRI systems available from different manufacturers in order to make an intelligent selection of size and features that will result in a technical, economical success.

For the most part, the Army has selected starved-air units because, in the typical size used (under 50 TPD), this equipment requires no additional devices for pollution control. Other systems need, as a minimum, particulate control. Now, with the changing

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[1]S.A. Hathaway and R.J. Dealy, *Technical Evaluation of Army-Scale Waste-to-Energy Systems*, Interim Report E-110/ADA042578 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], July 1977); S.A. Hathaway, *Recovery of Energy From Solid Waste at Army Installations*, Technical Manuscript E-118/ADA044814 (USA-CERL, August 1977); S.A. Hathaway, *Application of the Package Controlled-Air, Heat Recovery Solid Waste Incinerator on Army Fixed Facilities and Installations*, Technical Report E-151/ADA071539 (USA-CERL, June 1979).

legislation concerning acid gas emissions, starved-air technology may not be the best choice in all cases.

Objective

The objective of this work is to provide the most comprehensive and technically detailed review possible of all available HRI equipment. This report is intended not only to allow DEHs and DEs to see the range of equipment offered by each manufacturer, but also to see what is the apparent industry norms for that type of equipment.

Approach

The literature in the field was reviewed thoroughly. A survey was developed and sent to nine manufacturers, while information on many other companies was obtained from the Naval Civil Engineering Laboratory, the U.S. Air Force, and Argonne National Laboratory. Altogether about 30 manufacturers were studied.

The manufacturers and their equipment were then grouped into four categories: starved-air modular, rotary kiln, excess-air grate, and fluidized bed combustion (FBC). The characteristic process for each group was defined. Especially interesting or unique aspects of each product were noted, and technical characteristics of all equipment were then compared. Finally, the general design characteristics were summarized for each equipment category.

Scope

Since this study primarily concerns equipment capable of burning waste in a way that will allow recovery of useful heat, equipment for producing refuse-derived fuel (RDF) was not considered. All technologies covered except FBC will burn refuse with no prior preparation except removal of bulky items. FBC requires only shredding and air classification to the extent necessary for feeding and bed retention. Also, since individual incinerator units of primary interest to the military are in the size range 20 to 75 ton/day (18 to 68 tonne/day), European grate units (e.g., Martin and Von Roll) were excluded as being generally too large. This size limitation is based on an average of 30 to 60 ton/day waste generated at the typical Army installation. All manufacturers that could be identified were included to determine (among other aspects) if their products fell within this range. Economics of the equipment also were not considered; that analysis was beyond the scope of this report.

Information in this report is intended to serve as a reference to state-of-the-art HRI equipment and should not take the place of a complete, site-specific evaluation for determining applicability of a system. Finally, it should be noted that most technical information came from manufacturers in the form of promotional material and may not be an accurate representation of actual system operation.

Mode of Technology Transfer

It is recommended that the information in this report be used to update Corps of Engineers Guide Specification (CEGS) 11171, *Packaged Controlled Air Incinerators* (December 1981), to provide a more current listing of the industry norms.

2 PROJECT PLANNING

Groundwork

The first HRIs constructed by the Army were funded as energy conservation projects (alternative energy) under the Energy Conservation Investment Program (ECIP). These projects failed to meet the very specific criteria of that program with regard to savings from energy production. Currently, HRI projects can be built under Military Construction, Army (MCA) funding in response to a waste disposal problem (e.g., landfill shortage or increased contractor fees). Energy benefits certainly must be considered in the economic analysis of a potential project, but the primary purpose must be to solve a waste disposal problem.

Another issue to consider is the possible use of a commercial HRI facility that would be built near, or on, the military installation. The installation may be a good candidate as primary energy customer for such a "third-party" facility. However, construction of these plants normally requires local government involvement and support which may not materialize fast enough to solve the disposal problem.

Should it be decided that an HRI constructed by the Army is the required solution, the DEH and DE must recognize the limitations of these plants and the problems involved in designing and operating them.[2]

Project Inception

Prior to considering what combustion technologies could be used to relieve the waste disposal problem, the amount of waste generated must be determined accurately along with its characteristics.[3] The waste should be weighed for 2 weeks or more, four times within a 1-year period. Visual estimation of the amount of waste or random weighing of a few trucks is not adequate. Large-scale errors have occurred in the past as a result of using these methods. In addition, seasonal variation in the waste supply must be identified and considered in the measurement. However, visual methods and source identification may be used for *characterizing* the waste; see Technical Report E-75. Most military troop and training bases will produce 30 to 60 TPD of waste that is better than IIA Type 2* (4300 Btu/lb). Depots and other industrial activities will generate a lesser quantity, but it may be closer to IIA Type 1 (6500 Btu/lb).

After the amount of waste and its approximate heat content are determined (based on its characteristics), uses for the thermal output must be determined. Each ton of waste processed will produce approximately 4000 lb of 150 psig steam, depending on the heat content. The minimum seasonal steam load should be equal to the normal operational capacity of the plant. If it is not, provision must be made for condensing the excess steam, and less than full use of the steam production during certain periods must be considered in the economic assessments. There also must be adequate physical space available near the steam load for the plant site.

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[2]R. A. Ducey, et al., *Heat Recovery Incineration: A Summary of Operational Experience*, Special Report E-85/06/ADA152236 (USA-CERL, 1985).

[3]Consult G. Schanche, L. Greep, and B. Donahue, *Installation Solid Waste Survey*, Technical Report E-75/ADA018879 (USA-CERL, October 1975).

*Incinerator Institute of America (IIA) classification.

Environmental Considerations

Local environmental guidelines are critical to consider in selecting the combustion technology and to the ultimate success of a project. Because the regulations are changing in many states, it is important to consider the most current version available. General information on state regulations, air pollution aspects of the various technologies, and particulate control devices can be found in a USA-CERL Technical Report.[4] However, the local Environmental Protection Agency (EPA) must be contacted to determine the most current situation for present and future guidelines.

In states requiring acid gas control, the guidelines may be as stringent as limiting emission content to less than 30 ppm hydrochloric acid (the predominant acid), and/or 90 percent hydrochloric acid gas capture. The preferred technology is a "spray-dry absorber" followed by a baghouse. This configuration involves spraying a lime slurry into a large reaction chamber, countercurrent to the gas flow. The cooler, moist flue gas then passes through the baghouse which collects the particles of ash and dried lime as well as capturing some additional acid gas. A major drawback with this technology is that it does not scale down very economically to sizes of interest to the Army and may increase the capital cost of the plant by as much as 50 percent. Another technology, which is much less expensive, is dry-lime injection into the ductwork ahead of the baghouse, with all of the acid gas captured through the lime cake on the bag filters. As of spring 1987, Interel, Wheelabrator Frye, Flakt, and Research Cottrell were producing this design and guaranteeing 90 percent capture.

Technology Selection

Once the preliminary stages are completed, the DEH and DE can start evaluating the alternative technologies. Chapters 3 through 6 should be reviewed for details of the four types of systems and their manufacturers. It must be stressed that this information should be consulted only to provide a starting point for a more thorough investigation to follow. It must not be relied upon in making the final decision for selecting a system.

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[4] M. Savoie, G. Schanche, and W. Mikucki, *Air Pollution Aspects of Modular Heat-Recovery Incinerators*, Technical Report N-86/04/ADA166054 (USA-CERL, January 1986).

3 STARVED-AIR UNITS

Process Description

The starved-air technology is by far the most popular. The simple, modular construction and the usual lack of any requirement for separate air pollution control equipment make these systems the least expensive in most cases. However, this situation is changing as various states begin to restrict acid gas emissions.

Figure 1 shows a typical starved-air unit. Waste is normally fed through a fire door into a primary chamber where it is pyrolyzed and burned under substoichiometric conditions and a low temperature of about 1600°F. This pyrolysis action produces carbon monoxide (CO), hydrogen (H_2), and other hydrocarbon compounds. Steam is sometimes injected for temperature control and to produce a water-gas reaction that complements the pyrolysis. The steam reacts with the hot fixed carbon to produce additional CO and H_2. All of this action results in very little nitrogen oxide (NO_x) formation. In addition, gas velocities in the primary chamber are kept very low so that little particulate matter is carried out of the chamber with the hot gases. Internal rams or other devices move the waste gradually to the other end of the chamber where it is removed as ash. This minimal agitation and mixing of the waste also helps to minimize particulate carryover. However, to achieve a reasonable burnout, waste retention times of 4 to 6 hr are needed.

Gases from the primary chamber are vented to a secondary chamber, where a large amount of excess air is added to ensure complete combustion of the partially burned gases during a retention time of up to 2 sec. A gas- or oil-fired burner is always present in this chamber to ensure the high temperatures (1800 to 2000°F) needed to complete combustion. Most particulates that enter this chamber are caused to slag and fall out of the gas stream due to the high temperatures. Normally, the gases are then vented to a heat recovery boiler to produce steam. However, an alternative path (dump stack) usually is provided in case steam is not required or the boiler is out of service but the waste must still be burned.

Some advanced designs are being developed by Consumat and Comtro, among others. These units preheat the combustion air and/or feedwater in passages inside the refractory in the primary chamber.

Manufacturers

Fifteen manufacturers were identified for this type of equipment. Appendix A lists the technical data on each design.

Atlas

Atlas Incinerator is currently selling the Econo-Therm design. This company apparently considers most of its design details to be proprietary. However, the Atlas brochure shows a unique feature--external access to the under-fire air ports for cleaning. Outdoor installation (incinerator external to the building) seems to be this company's typical application. The firetube boiler illustrated in the brochure is single-pass type and very long. The secondary chamber features a combustion tunnel, followed by a number of baffles. It appears that a common stack is used. The 60 units claimed to be in service should provide good historical performance information on this equipment over time. However, the size range (12 to 24 TPD) seems very narrow, and the steam pressure (11 to 80 psig) is quite low.

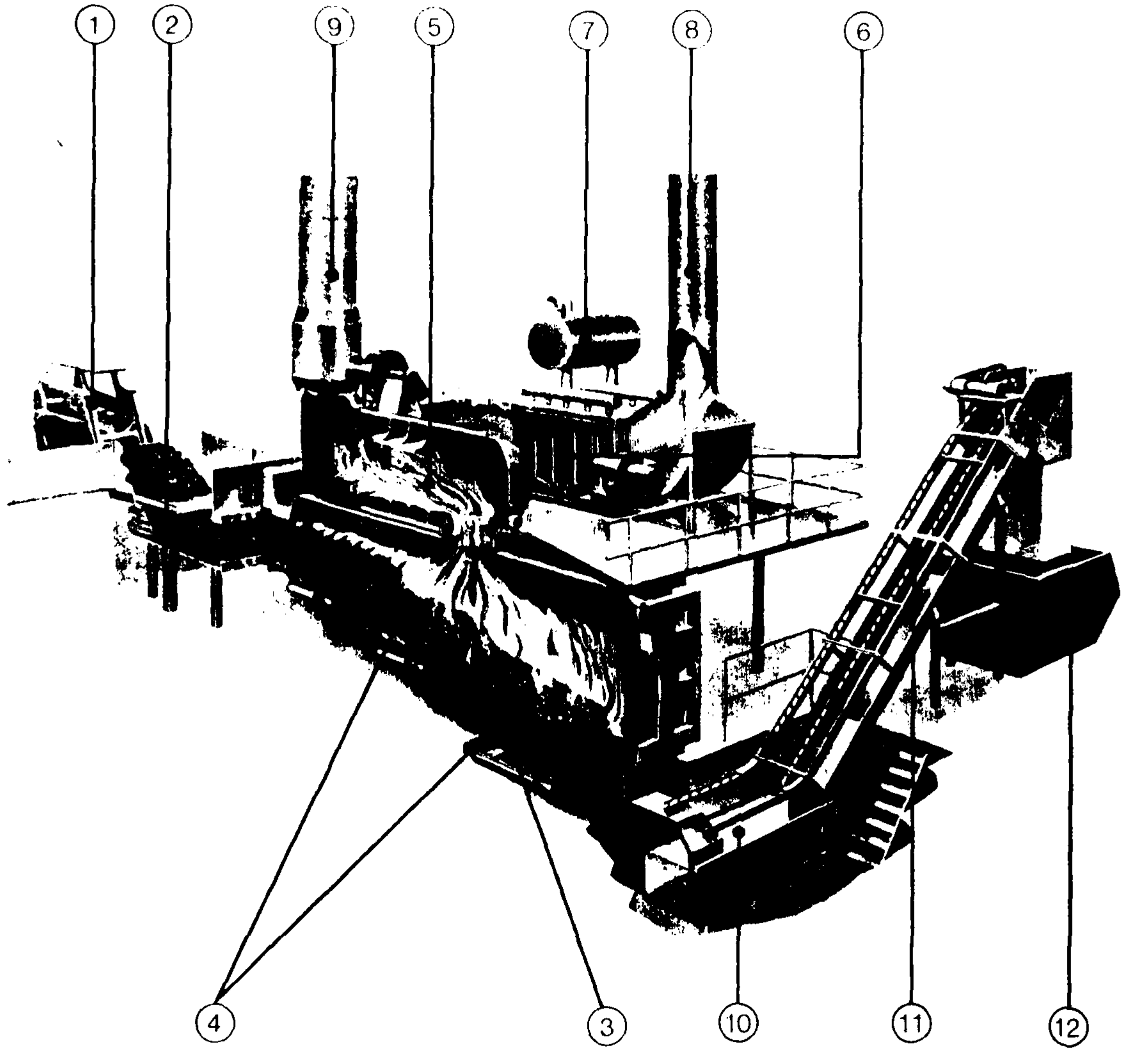


Figure 1. Typical modular starved-air incinerator. Material and hot gas flows are controlled to provide steam from solid waste as follows. A skid steer tractor (1) pushes the waste to the automatic loader (2). The loader then automatically injects the waste into the gas production chamber (3) where transfer rams (4) move the material slowly through the system. The high-temperature environment in the gas production chamber is provided with a controlled quantity of air so that gases from the process are not burned in this chamber but fed to the upper or pollution control chamber (5). Here the gases are mixed with air and controlled to maintain a proper air fuel ratio and temperature for entrance into the heat exchanger (6) where steam is produced. A steam separator (7) is provided to ensure high-quality steam. In normal operation, gases are discharged through the energy stack (8). When steam is not required or in the event of a power failure, hot gases are vented through the dump stack (9). The inert material from the combustion process is ejected from the machine in the form of ash into the wet sump (10) and conveyed (11) into a closed bottom container (12) which can then be hauled to the landfill for final disposal.

Brulé

Brulé has a unique three-chambered design to ensure complete combustion and features separate energy and dump stacks. However, little technical information is available on their equipment. There is an indication that Brulé routinely supplies a cyclone which may indicate flue-gas dust loadings higher than normal for this type of equipment. The recommended operating time of 5 days/week also suggests that more maintenance is needed relative to most other manufacturers' products.

Burn-Zol

Burn-Zol apparently produces very small, vertically stacked units for the most part rather than the more typical horizontal chamber design. The horizontal design the company does offer probably is an expansion of its product line and is equipped with separate energy and dump stacks. The manufacturer claims that a very small amount of auxiliary fuel is needed. The gunite refractory no doubt contributes to the low refractory life of 2 to 10 years. The 1:20 turndown seems unusually large. The spray ash quench system can work if large amounts of water are used. The number of operators required (three) may indicate a more labor-intensive operation than the other products.

Clear Air

Clear Air produces both starved- and excess-air units and has used the Synergy trademark which, along with the Clear Air design, was licensed for a time to a company in New York. Rather than internal rams, these systems use a grate system which also enhances the underfire air distribution. Separate energy and dump stacks are used. The expected thermal efficiency of 40 percent is significantly lower than that claimed by the other manufacturers. The primary chamber temperature, 1800°F, is hotter than normal and usually is an indication that substoichiometric conditions have not been achieved. The ash conveyor is very large, heavy, and returns over the top of the primary chamber.

Cleaver Brooks

Cleaver Brooks apparently has purchased Kelley and is selling these incinerators under the Cleaver Brooks name, even though Kelley still manufactures them. Based on the number of units claimed to be in operation, this manufacturer seems to be the second most popular. However, the reported life expectancy seems a little low. The design uses a single stack and its secondary chamber appears to be an expansion in the exhaust ductwork. The recommended cart dumper waste retrieval system usually would be specified only for very small, onsite, industrial applications. Cleaver Brooks was the only manufacturer showing a major concern for the amount of glass in the waste. Auxiliary fuel requirements for these units seem high.

Comtro

Comtro is associated with the John Zink Corp. Comtro's units may operate in an excess-air mode during startup, have a special baffle in the secondary chamber for better gas mixing, and use separate energy and dump stacks. However, very little detailed technical information was available from this manufacturer. There is some indication that keeping ash cleaned out from behind the internal rams may be critical to maintaining starved conditions in the primary chamber.

Consumat

Consumat is the most popular manufacturer based on the reported number of units in service. This company's brochure is very descriptive and includes example plant layouts and dimensions. Multiple internal rams, separate energy and dump stacks, and a wide variety of equipment combinations ("packs") are typical design features. The wide range of unit sizes (5 to 100 TPD) may be related to their "pack" concept of having more than one primary chamber feed into one secondary chamber. Consumat requires that its own personnel operate the equipment for the first year in service to minimize warranty claims. The company also is willing to design, build, and maintain ownership of the plants under sponsorship of a local waste authority. It is claimed that no auxiliary fuel is needed once normal operating conditions and temperatures are established. The high maximum steam pressure and temperature reported are typical for operation with a watertube boiler. This manufacturer is the only one that provided data on ash-water solids content (30 to 40 percent).

Enercon

No data from Enercon are included in this study because the company has no formal product line and its units are generally too large for use on military installations. Although they are "starved-air" design, these units involve much field construction, are custom-designed for each project, and normally are larger than 75 TPD. Enercon is closely associated with Vicon Recovery, a designer-builder-operator company.

Ecolaire Combustion Products (ECP)

Ecolaire formerly was named Environmental Control Products before a change in ownership. ECP normally uses only one internal ram and now offers a "backhoe" arrangement for ash removal. Separate energy and dump stacks are employed. ECP is a full-service company that will design, build, and own an HRI plant as well as operate it for a local waste authority. The life expectancy seems somewhat long at 20 years, but this company is claiming an availability of only 85 percent. Steam injection is listed as one method for maintaining primary chamber temperature, which may allow a water-gas reaction to occur under substoichiometric conditions. The high maximum steam pressure and temperature reported are typical for operation with a watertube boiler. The projection given for uncontrolled particulate emissions is relatively high.

Simonds

Simonds uses a single stack. Although a large number of Simonds' units are claimed to be in service (200), all applications are industrial. No information is available on the type of waste burned. The cart-dumper waste retrieval system recommended is typical of small industrial operations. A water ash-quenching system is included in the design, but the unit is claimed to produce no ash wastewater. Simonds is one of the two manufacturers of this technology that claim no response to steam demand, which may actually be more realistic than other claims. The firing rate being controlled by "draft" is unique and may bear further investigation.

Stock Equipment

Stock Equipment Co. produces a very compact model with both chambers in one housing and on one level. A single stack appears to be used. The unit size range claimed is large at 3.6 to 100 TPD. The description of the feed system is vague; these systems may involve some type of chute rather than a "silo." The maximum primary chamber

temperature, 2000°F, is too high for starved-air conditions. The screw-auger bottom-ash removal system may have a problem handling metal wire and banding. The hot cyclone is an interesting device to supply with this equipment if it is located before the boiler and reduces the ash accumulation in the firetubes. No emissions data were provided.

Therm-Tech

Therm-Tech features separate energy and dump stacks along with pathological incinerators. The company is willing to contract for operating its units, but since it has only two units in service for burning municipal solid waste (MSW), it would be difficult to determine a track record. The size range seems somewhat narrow. Although a "moving hearth" is indicated in the design, no details are available. The primary chamber temperature seems very low, but not unreasonable if combustion can be sustained. The lower temperature limit for the secondary chamber also seems too low at 1600°F. A spray system is used to quench the ash, which would work if enough water is added. The 10:1 turndown ratio may be too large. This manufacturer projects a hydrochloric acid gas emission at 50 ppm which is the only such data available from all companies surveyed.

UIP Engineered Products

UIP, a subsidiary of Eastmet, has produced industrial process equipment for many years, but only recently has entered the incinerator business using a design developed by two college professors. The design emphasizes strict control of combustion air. Primary air is introduced through an inclined vibrating grate. The secondary chamber consists of the ducting that leads from the primary chamber and contains fans and burners. Before entering the boiler, gases pass through a settling chamber that includes a perforated plate. The energy recovery stack is mounted with its base inside a chamber which requires the gases to make about two turns and may even induce some cyclonic action for additional particle separation. A separate dump stack is used. The expected thermal efficiency is higher than values reported by other manufacturers.

U.S. Smelting Furnace Co.

This company makes the Smokatrol brand of incinerators which use a common stack. An optional gas/oil burner is available to allow the waste heat boiler to produce steam when the incinerator is not operating. The company reported that all its units were sold for industrial use, but there are only three in operation. U.S. Smelting produces one of the smallest units available at about 2 TPD. The company indicates that noncombustibles should be removed from the waste (preprocessing) to minimize glass and metal reaching the incinerator. The auxiliary fuel requirements (200 gal/ton waste) translates into 26 MBtu/ton, which is a very large amount. The all-castable refractory (no firebrick) probably accounts for the somewhat short life expectancy of 3 to 5 years. The upper limit of 350 psig for steam pressure is slightly above the normal expectations for firetube boilers. A spray system is used to quench the ash, which would work if enough water is added. The 10:1 turndown ratio seems too large. The recommended operating time of 5 days/week may indicate that more maintenance is needed relative to most other manufacturers' products.

Washburn & Granger

Washburn & Granger produces the Dean brand of HRI and is oriented mainly toward destroying pathological wastes. The clamshell reported as the recommended waste retrieval system is normally not used with small incinerators. The secondary chamber

temperature seems too low at 1500°F, and may be the reason why a scrubber usually is supplied. No information was provided on the type of refractory used but its expected life is somewhat short. Washburn & Granger is one of the two manufacturers of this technology that claimed no response to steam demand for the units, which may be a more realistic statement than other claims. The 10:1 turndown ratio seems too large.

Equipment Comparisons

General Characteristics

Some of the equipment characteristics for this technology vary considerably due to the large number of companies. These manufacturers claim to sell from 1 to 300 units per year, with 5 to 15 being typical. Most units appear to be sold for industrial purposes --probably because such waste streams are usually well defined and more homogeneous than for other applications. Consumat claims to have the largest number of units in operation (2000+) followed by Cleaver Brooks (Kelley) (1000), but some of these units are extremely small and are designed for incineration only.

Several manufacturers will contract to operate their units; Consumat demands such an agreement for a certain period of time because of operator training problems. The units are projected to last from 5 to 20 years, with 10 to 15 years appearing to be the average. The average estimated availability (i.e., the fraction of possible operating time during which the unit is actually available for operation and not out of service as a result of a failure) is typically reported by the manufacturers to be 90 percent. Sizes range from 2 to 100 TPD of waste and 1000 to 50,000 lb/hr of steam. Claimed thermal efficiency varies from 40 to 74 percent, with the most common values reported between 55 and 60 percent. Some units feature a system for preheating combustion air.

Feed Systems

Most manufacturers recommend front loaders for waste retrieval, although Cleaver Brooks recommends cart dumpers, which would be typical for a very small facility located at the source of the waste. Removal of bulky items is usually the only preprocessing required. Cleaver Brooks, however, recommends removal of almost all glass, which could be a tedious process.

Feeding can be on a continuous or batch basis and is normally done with a ram, although Atlas and Therm-Tech use a conveyor. Feed-system-related outages (i.e., the fraction of possible operating time that a unit is not functional due to a failure) are claimed by the manufacturers to be 1 to 5 percent.

Maximum allowable moisture content in the waste ranges from 25 to 70 percent (40 percent average) with some manufacturers not reporting a limit. Allowable ash content can be as high as 40 percent (Consumat), but 10 to 15 percent seems typical. Average glass content has a limit of 10 percent, but there is no clear limitation on metal content. Special lubrication may be needed in some cases. There is such wide variation in the amount of supplemental fuel required (0 to 1.2 MBtu/ton) that no definite value is apparent.

Combustion Zone

Although internal rams are the most common method of moving waste through the incinerator, reciprocating grates are also used. Underfire air may be introduced through the rams (or grates) by means of ports located in or near the bottom of the incinerator floor. There is wide variability in grate heat release rates from those manufacturers citing a value. Carbon burnup ranges from 90 to 99 percent (95 percent average). Primary combustion zone temperature ranges from 1000 to 2000°F with an average of 1400°F. This temperature is usually controlled through the waste feed rate and the air supply, but water injection, steam injection, and "start-up burners" also are used. Secondary combustion zone temperatures range from 1500 to 2200°F with an average of 1800°F. Castable and brick refractories are the most common types used and have projected life expectancies of 5 to 15 years.

Boiler

Both firetube and watertube boilers are used, but the firetube units are the most common. Most manufacturers apparently have no data showing the heat transfer rate inside the boilers. Both manual cleaning and soot blowers are used, including soot blowers on the firetube units. Steam can be produced in a range of 11 to 600 psig with temperatures from saturation to 600°F. Feedwater consumption has not been quantified, and blowdown can be either automatic or manual in most cases. Boiler-related outages are claimed to be 1 to 2 percent.

Ash System

As would be expected, very little flyash is produced by this technology. Ash is normally removed by ram and conveyor, except for the Stock unit, which uses a screw auger. Water and mechanical methods are both used to seal the ash hopper. Ash-system-related outages are claimed to be 1 to 5 percent which does not reflect actual experience[5] showing ash conveyors to be a high maintenance item. Both spray and quench systems are used for cooling the ash. Most of these manufacturers recycle the ash water.

Controls

Automatic controls are the most common, but semiautomatic controls also are used. Most manufacturers claim that their unit can respond to steam demand, usually by bypassing hot gases past the boiler. Stringent environmental requirements in some states may not allow this to be done. Temperature is the usual method of controlling the firing rate. CO and O_2 monitors are not usually provided, but some manufacturers will supply them if desired. Fans are controlled by dampers. Turndown ratios claimed by the manufacturers vary from 2:1 to 10:1 (e.g., Therm-Tech, US Smelting, and Washburn & Granger). One or two operators are required per shift in most cases. Control-related outages are claimed to be only 1 percent.

Environmental

Pollution control devices are not normally required for this technology unless the state has established acid-gas control requirements. Uncontrolled particulate emissions

[5]R. Ducey, et al.

for the units range from 0.13 grains per dry standard cubic foot (gr/DSCF) to 0.08 gr/DSCF. Much less attention has been given to other pollutants and little information is available. Scrubbers can be supplied for special needs.

Operation

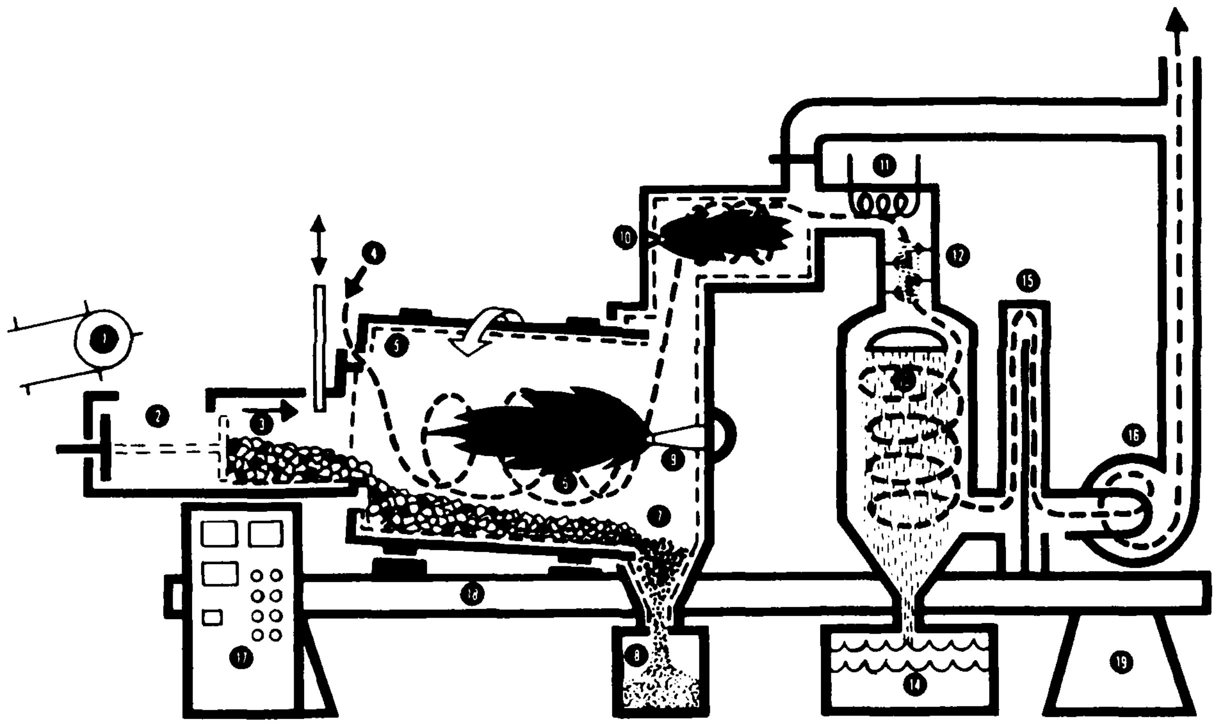
Normally, only one operator is required, although a second may be needed. A mechanic usually need not be on hand, but should be on call. In some cases, a laborer also may be required. Most units are designed to be operated 3 shifts/day, 6 or 7 days/week.

4 ROTARY KILN

Process Description

Rotary kiln technology involves a chamber that rotates to agitate the waste and expose it to the combustion air. Figure 2 shows a typical rotary kiln unit. The chamber is tilted slightly to allow the waste to move from the high end, where it is fed to the lower end, at which point the ash is discharged.

The kiln can be operated in either a "controlled-air" (starved) or excess-air mode. Gases in the controlled-air units pass into a secondary combustion chamber where additional air is added and a burner maintains a set temperature in the same way that a starved-air unit operates. Both types of units finally vent the gases into an attached boiler.



1 Material handling system
2 Auto-cycle feeding system: feed hopper, door, ram feeder
3 Waste to incinerator
4 Combustion air in
5 Refractory-lined, rotating cylinder
6 Tumble-burning action
7 Incombustible ash
8 Ash bin
9 Auto-Control Burner Package: programmed pilot burner
10 Afterburner chamber
11 Heat Recuperation
12 Precooler
13 Scrubber Package: stainless steel, corrosion-free scrubber, wet or dry
14 Recycle water, fly ash sludge
15 Neutralization column
16 Exhaust fan and stack
17 Self-compensating instrumentation and controls
18 Support frame
19 Support piers

Figure 2. Typical rotary kiln incinerator.

Manufacturers

Six companies have been identified as producing this type of equipment. However, not all of these manufacturers produce a unit that is strictly a "kiln," but they have been included in this group because their equipment is very similar to a kiln. Details of these products are in Appendix B.

C-E Raymond

C-E Raymond, a subsidiary of Combustion Engineering, apparently has absorbed the Bartlet-Snow Company. C-E Raymond claims the second largest number of units in operation so that a track record should be available and easy to evaluate. The size range of these units is quite large at 13 to 320 TPD. There reportedly are no restrictions on the amount of water, ash, or metal in the waste; the variable amount of auxiliary fuel required could compensate for the waste quality. The wide range of operating temperatures suggests that the system may operate under substoichiometric conditions at times. The refractory life (6 months to 10 years) varies widely. The claim of infinite turndown is inconsistent with the lack of response to steam demand. In addition, uncontrolled particulate emissions of 0.08 gr/SCF are not consistent with a 30 percent opacity.

Giery

Giery is actually a basket-grate system and the company has been sold to Peabody Gordon-Piatt. This product is mentioned several times in the literature, but no specific technical information is available; thus, it is omitted from most of the tables in Appendix B.

Industrionics

Industrionics uses the tradename Consertherm and produces controlled-air units. The 30 units said to be in service are split evenly between industrial and municipal applications. This company produces one of the smallest units at 2.7 TPD. The auger option for the feed system may be a problem because augers are prone to jamming when exposed to wet waste and/or wire. The pump option would be needed for burning sludges; under this condition, it would be difficult to maintain combustion without adding auxiliary fuel (the company claims no such fuel is needed). The secondary combustion zone temperatures, 2200 to 2400°F, are very close to the level at which NO_x are produced. Air-cooling of the bottom ash is a unique feature among these manufacturers.

O'Connor

O'Connor is owned by Westinghouse and its design probably is the most publicized in this group. The kiln is a unique water-wall design. Even though this design is not characteristic of any other equipment of this type, it is the design most commonly associated with this technology. O'Connor claims that most of its inservice units are burning municipal waste. This company also projects the longest life expectancy for its unit compared with the others. The ram feed system usually involves a chute and may be prone to jamming. Air is injected through slots in the kiln wall from under the waste rather than just allowing the tumbling action to provide contact. Temperatures in the kiln (2600 to 2900°F) are conducive to NO_x formation. The steam pressure can be high enough to allow electrical cogeneration. O'Connor is the only manufacturer that claims response to steam demand. The fans are variable-speed-controlled which raises the capital cost, but provides better energy efficiency than do other designs.

Therm-All

Therm-All produces a controlled-air unit with a physical construction strongly resembling a starved-air system. All operating units are said to be used in industrial applications, but only five are in service. This company estimates the lowest life expectancy compared with the other units and seem to concentrate on small units. Thermal efficiency expectations are lower than those of the other manufacturers. Apparently, most Therm-All equipment is custom-designed, with variable characteristics. The uncontrolled particulate emissions are high and not consistent with 0 percent opacity.

Trofe

Trofe Incineration uses a unique cylinder that rocks through a 210-degree arc. Although there is no indication that these units are operated in a starved-air mode, the combustion temperatures would suggest excess-air operation; an after-burner chamber is provided to ensure complete destruction of the wastes. This company reports having only one unit in operation. The use of a conveyor for the waste retrieval system is not a typical design. The pulse feed system seems unique and is not explained clearly. There are limits on moisture, glass, and metal content in the waste. The claimed refractory life is the lowest of all manufacturers. The reported 4:1 turndown seems high. No information is supplied on air pollution control devices and their effects.

Equipment Comparisons

General Characteristics

If the information gathered on this technology is accurate, significant numbers (7 to 10) of this type of incinerator are sold each year. Most applications have been for industrial wastes, although most of the manufacturers also claim the unit's ability to burn municipal solid waste (MSW). Three of the six (O'Connor, Therm-All, and Trofe) offer to operate their units.

C-E Raymond and Industrionics reportedly have the largest number of units in service (20 and 30, respectively). Life expectancies are projected to be 10 to 30 years (20 average) with an availability of 80 to 96 percent (88 percent average). Available sizes cover a considerable range--2 to 320 TPD of waste and 720 to 72,000 lb/hr of steam. Thermal efficiency ranges from 50 to 75 percent with 70 percent being the most typical value. The combustion air usually is preheated.

Feed Systems

Apparently there is no recommended waste retrieval system for this technology. Although C-E Raymond specifies that some of the waste should be shredded, most other manufacturers require no preprocessing. Feeding usually is done on a continuous basis using a variety of devices including rams, augers, and pumps for sludges. Moisture content in the waste has a predominant limit of 50 percent, although some manufacturers do not limit this value. There also are no limitations on the ash, glass, and metal contents. The feed systems are said to require no special maintenance. Supplemental fuel may or may not be required to sustain combustion.

Combustion Zone

The O'Connor unit has holes in the kiln for introducing underfire air, but the others rely on agitation of the kiln for contact between waste and combustion air. The grate heat release rate apparently has not been investigated by most manufacturers. Carbon burnup is indicated as 93 to 98 percent. The primary combustion zone temperature varies from 1400 to 2900°F (the larger value being indicative of excess air operation) and is controlled by feed rate and air modulation.

Secondary combustion zone temperatures range from 1600 to 2800°F. The very low numbers for the O'Connor unit reflect the high heat absorption rate of the water-wall boiler used with that kiln. The other manufacturers use fire- or watertube heat recovery boilers that have lower absorption rates. Combustion-related outages are claimed to be rare. Refractories have a very short life expectancy as a result of the high degree of mechanical stress inherent in this technology.

Boiler

Watertube, water-wall, and firetube boilers are used, but the heat transfer rate is not well defined. This value is important with respect to the potential for slagging of particulates when the flue gas temperature exceeds 2000°F as in the case of the C-E Raymond, Industrionics, and Trofe units. Steam pressure ranges from atmospheric to 800 psig with temperatures to 750°F. This technology could be used for cogeneration. Feedwater consumption and blowdown requirements are not well defined. Boiler-related outages are claimed to be infrequent.

Ash System

Both wet and dry bottom-ash systems are used. Little information is available on details of the associated ash removal mechanisms.

Controls

Automatic controls are the most common type cited, but response to steam demand usually is not provided. These controls seem to primarily serve to maintain steady-state firing conditions. Firing rate usually is controlled by temperature. CO and O_2 monitors are not normally provided. Fans are usually controlled by dampers as opposed to variable-speed motors. Turndown ratios reported for the units vary from 2:1 to 4:1, with C-E Raymond claiming an infinite turndown. One to two operators usually are required per shift for one unit. Few control-related outages are claimed.

Environmental

All manufacturers normally provide pollution control devices, but Industrionics lists them as optional. The listing as optional is probably because the Industrionics units are operated in a controlled-air mode. C-E Raymond, Industrionics, and Trofe apparently have uncontrolled particulate emissions that are acceptable in most states at 0.08 gr/DSCF. Controlled particulate emissions can be as low as 0.005 gr/DSCF largely through the use of a baghouse. Little information was reported concerning NO_x emissions, but the formation of these compounds generally depends on primary combustion zone temperature and whether oxidizing or reducing conditions exist. There is also a lack of information available on chloride emissions, opacity, ash-water solids content, and other pollutants in the ash water. Special pollution control devices are sometimes used; these include O_2, CO, and CO_2 monitors for Industrionics.

Operation

Usually two operators, one mechanic, and one or more laborers per shift are needed for a single unit. Most units can be operated 3 shifts/day, 7 days/week, although Industrionics expects its equipment to operate only 5 days/week.

5 EXCESS-AIR GRATE

Process Description

The process involved with the excess-air grate system is relatively simple, with only three major steps:

1. Waste is dumped onto the grate by the feeding system.

2. The grate then moves the waste along and air in excess of stoichiometric requirements is added by overfire and/or underfire air ports to help achieve total combustion.

3. The waste, after completing combustion, is then dumped into an ash storage bin where it is quenched by cooling water. The ash is then conveyed to another container for ultimate disposal.

Figure 3 shows a typical excess-air grate unit.

Manufacturers

This study identified five companies that build excess-air grate systems. The data on each design are in Appendix C.

Basic Environmental

Basic Environmental has a unique pulsed (shaken) hearth design. The arrangement in use, although it is basically an excess-air unit, features staged combustion and can be built to include a provision for cogeneration of electricity. This company claims that 85 percent of its 18 units are burning industrial waste. Basic's method of preheating combustion air by direct contact with the flue gas was not explained. It is claimed that no supplemental fuel is required unless the waste is of very low quality. The primary combustion zone temperature (1600°F) is consistent with starved-air operation. The refractory life expectancy has a very wide range and the maximum steam pressure limit indicates that some cogeneration is possible. The backhoe ash removal system is a unique feature and this manufacturer seems to have been the first to use it. Response to steam demand is claimed for these units. The reported 4:1 turndown ratio seems high. Because of the complexity of this equipment, the specified requirement for one operator may be inadequate.

Clear Air

Clear Air makes both excess-air and starved-air units. For more details, see the corresponding section in Chapter 3.

Detroit Stoker

Detroit Stoker Company manufactures grates and other combustion equipment for use with other companies' boilers. Detroit Stoker claims that most of its units are sold for municipal use. The long life expectancy reflects the rugged construction and repairable grate. There also is a very wide size range available. The recommended clamshell waste retrieval system is the usual design for large plants. The 2200°F combustion

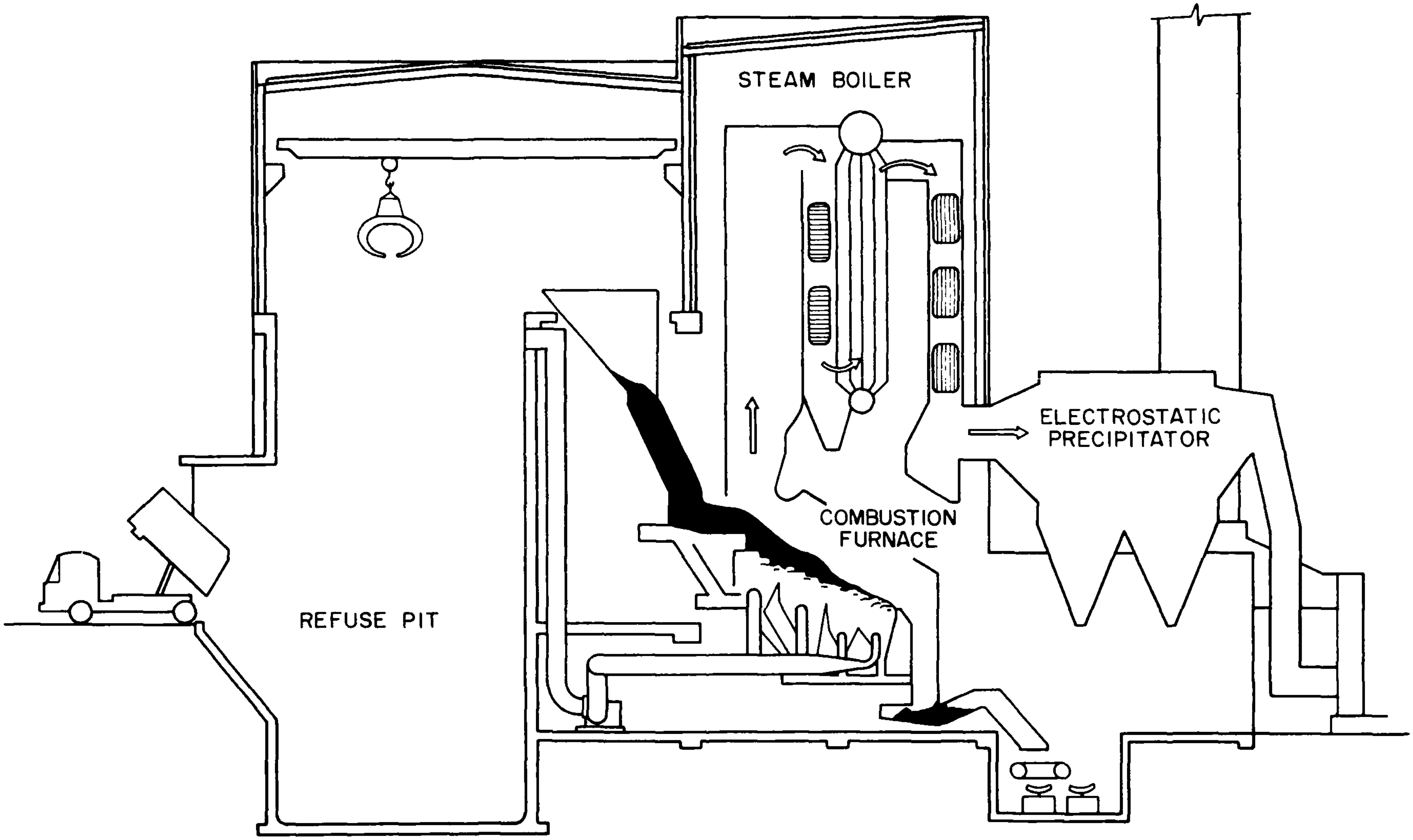


Figure 3. Typical excess-air grate incinerator.

temperature is typical for excess-air operation, and the silicon carbide refractory is normally applied to the walls of the furnace area to help maintain that temperature. No information is available on the boiler, incinerator controls, and pollution control system since those components generally are supplied by other manufacturers. The claim of 90 percent bottom ash seems unrealistic for this technology.

Morse Boulger

Morse Boulger is another company that supplies combustion equipment for use with other manufacturers' boilers. This equipment can be set up to provide cogeneration of electricity. Morse Boulger claims that most of its units are sold for industrial use and the company will contract to operate. The extremely large number of units reported to be in service (1455) may date back many years and most of these units may not offer heat recovery. The available size range extends from units as small as 1 TPD up to 300 TPD. The expected thermal efficiency seems low for this technology. The allowable waste quality would indicate some sensitivity to metal content. The combustion temperature range suggests borderline substoichiometric operation. Little information is available on the boiler since this component usually is provided by other companies. Response to steam demand is claimed to be possible. The high uncontrolled emissions are due to the rapid, turbulent combustion typical of this technology.

Olivine

Olivine makes two styles of incinerators with add-on heat recovery. One is a "pile" type, batch process, and the other is a special hearth. Almost all are sold for industrial use, and the company will contract to operate. The number of units claimed to be in service is quite large at 100. Sheets or bricks of natural Olivine rock are used for the refractory and as a heat sink to maintain the combustion process. The use of "burning tires" to maintain a combustion temperature of 1800°F indicates that the process may not be very efficient.

Equipment Comparisons

General Characteristics

With the exception of Olivine, all of these heat recovery systems are the waterwall type. All systems can burn both industrial and municipal wastes. However, the manufacturers, with the exception of Detroit Stoker, tend to emphasize industrial wastes. Morse Boulger and Olivine are the only companies studied that offer to contract to operate their units. This finding is a little surprising considering the large number of units they have operating (unusually large in the case of Morse Boulger) because it is usually the smaller companies that offer this service as an incentive to sell more units.

The average life expectancy ranges from 20 years to a maximum of 40 years with an average claimed availability of 90 to 95 percent. Available sizes range from 1 to 1250 TPD of waste and 5600 to 250,000 lb/hr of steam, which is much more extensive than expected (this technology was not generally believed to have such small units available). Thermal efficiency varied substantially from 55 to 70 percent (Morse Boulger's 30 to 35 percent seems unusually low compared with values reported by the others). Combustion air is generally preheated. All manufacturers claim the ability to burn MSW.

Feed Systems

Feeding systems for these units showed some variety, with the smaller units (21 to 840 TPD) using a front loader while the larger Detroit Stoker units (50 to 1250 TPD) use a pit and clamshell. Some manufacturers require that bulky items be removed from the waste as the only preprocessing step, whereas others require no preprocessing. Olivine's units can use either a conveyor or a ram feeding system; all others use only a ram system for continuous feeding. The outage frequency for the feed system is claimed to be only 1 to 5 percent. The maximum allowable waste characteristics vary considerably at 30 to 60 percent for moisture, 25 to 40 percent for ash, 15 to 30 percent for glass, and 8 to 30 percent for metal. This variance points out the importance of developing an accurate characterization of the waste for this technology. The Basic Environmental unit requires supplemental fuel when the waste has a heating value of less than 4000 Btu/lb whereas the other units use supplemental fuel only for start-up.

Combustion Zone

Several hearth styles are employed to agitate the waste and move it through the combustion zone. In addition, underfire air is introduced into the combustion zone in a variety of ways such as by air jets, plenum, slots in the grate, or forced air. Heat release rates vary from 100,000 Btu/hr-ft^2 for the smaller units to 325,000 Btu/hr-ft^2 for the larger units. Expectations of carbon burnup are very consistent at 95 to 98 percent. Air limitation is normally used to maintain the primary combustion zone temperatures in the 1600 to 2200°F range (1800°F average) on all the units except for Olivine, which requires that tires be burned to control combustion. Only the Basic Environmental and Olivine units use secondary combustion zones in which the temperature ranges from 1700 to 2000°F. Virtually no combustion-related outages are claimed, although the grate refractory in the Basic Environmental units must be replaced frequently (every 2 yr).

Several different refractories are used: Olivine's special Olivine rock, silicon carbide, fire brick, and castable refractory (usually only for the first few feet up the waterwall). These refractories usually are claimed to last 10 to 20 yr, although Olivine does not know how long its rock will last since none have failed yet.

Boilers

Of these manufacturers, only Basic Environmental supplies boilers. Most of the others' combustion equipment is designed to be operated with another manufacturer's boiler.

Ash System

Most units have an ash-holding bin where the ashes are cooled with either spray or quench water. Basic Environmental uses a unique backhoe system to remove the ashes. Detroit Stoker and Morse Boulger use drag conveyors, and Olivine uses a ram to remove the ashes. The ash discharge is sealed by a variety of methods, including air pressure.

Controls

Basic Environmental and Morse Boulger supply automatic or semiautomatic controls, while Olivine supplies manual or semiautomatic controls. Response to steam demand can be achieved by changing the firing rate and/or bypassing the hot gases

around the steam generator when it is a separate heat recovery unit. Fans are controlled by dampers. The turndown ratio is typically 3.5:1, and normally only one operator is required per shift. Control outages range from 1 to 5 percent.

Environmental

Particulate control is normally required for this technology. The devices vary widely: electro-gravel filters, scrubbers, precipitators (ESP), and baghouses. These devices can bring uncontrolled emissions down from as much as 1.1 gr/DSCF to as little as 0.02 gr/DSCF, resulting in opacities of 20 percent (#1 Ringleman) for uncontrolled emissions to 3 percent for controlled emissions. NO_x ranges from 35 to 76.6 ppm. Other pollutants, including chlorides, are produced in amounts ranging from 10 to 200 ppm and until recently have not usually been controlled due to a lack of local regulation in most areas. However, scrubbers and other control methods can be used if required. Ash-water solids content can be as high as 50 percent; other pollutants in the water apparently have not been investigated.

Operation

Normally, one operator and one mechanic are required per shift. Units operate 3 shifts/day, 7 days/week.

6 FLUIDIZED BED COMBUSTION UNITS

Process Description

The basic fluidized bed combustion (FBC) process is fairly simple. Combustion air enters the lower portion of the combustor and passes through a grid that acts as a floor for the inert (usually sand) bed. This bed is kept in constant agitation by the rising air. Auxiliary fuel burners are used to heat the bed to the temperature required for igniting of the waste fuel.

Shredded waste is then fed into the bed. The "boiling and scrubbing" action of the sand/fuel mixture keeps the fuel in continuous contact with the combustion air. As combustion progresses, lighter fuel particles rise to the top of the bed and are consumed; heavier particles fall to the bottom and are routinely discharged. Heat is recovered and processed to steam or hot water by an integral or a waste-heat boiler. Figure 4 shows a typical FBC unit.

The two main advantages of using an FBC unit to burn waste are (1) low environmental emissions and (2) the combustor's insensitivity to fuel quality. However, a major impediment of FBC is the fuel preparation required prior to feeding it into the bed. Although beneficiation of the waste by removal of certain components is not required (with the possible exception of glass), bulk material has to be shredded, classified, and considered a form of refuse-derived fuel (RDF). RDF technology is still very experimental; the Air Force has done considerable work in this area.[6]

Manufacturers

Nine manufacturers were identified as producing FBC systems that do or potentially can burn waste. The data on each of their designs are summarized in Appendix D.

Combustion Power

Combustion Power, a subsidiary of Weyerhaeuser, has worked with the Department of Energy (DOE) to develop an FBC system that uses coal or RDF. However, besides this experimental unit, there is no real experience on which to evaluate Combustion Power's equipment. Most of these units are small and use a pneumatic feed system that could malfunction if the waste moisture content reaches 50 percent. The primary or bed temperature of 1400°F is low and the expectation of greater than 1400°F in the secondary, freeboard area indicates that some combustion may be occurring there. This design also requires the largest number of operators of the equipment surveyed.

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[6]Z. Kahn, M. Renard, and J. Campbell, *Investigation of Engineering and Design Considerations in Selecting Conveyors for Densified Refuse-Derived Fuel (dRDF) and dRDF:Coal Mixtures*, Final Report ESL-TR-81-58 (U.S. Air Force Engineering Studies Center [AFESC], August 1981); Rycon Inc., *Performance Analysis of Cofiring Densified Refuse-Derived Fuel in a Military Boiler*, Final Report ESL-TR-81-59 (AFESC, December 1981); W. J. Huff and R. K. McIntosh, *Management Impact Assessment of Refuse-Derived Fuel Implementation at Wright-Patterson Air Force Base*, Final Report ESL-TR- 81-56 (AFESC, March 1982).

Dorr Oliver

Dorr Oliver has had much experience with incinerating industrial wastes (mostly sludges) and, of the companies studied, has produced about 60 percent of the FBC systems currently in service. Keeler Boiler, which produces a unique vertical-tube FBC boiler design, was recently acquired by Dorr Oliver. Only about one-fourth of the Dorr Oliver units are claimed to be sold for industrial use, but probably not all 162 operational units are burning wastes. The typical unit size is large for applications in the Army. Temperatures in the secondary, freeboard area indicate that some combustion may occur there. The refractory life expectancy seems excessively long. The fluid bed ash cooler would make these units more thermally efficient than others, but also more complex. The option of either damper or speed control of the fans provides versatility in the design. The turndown ratio is small.

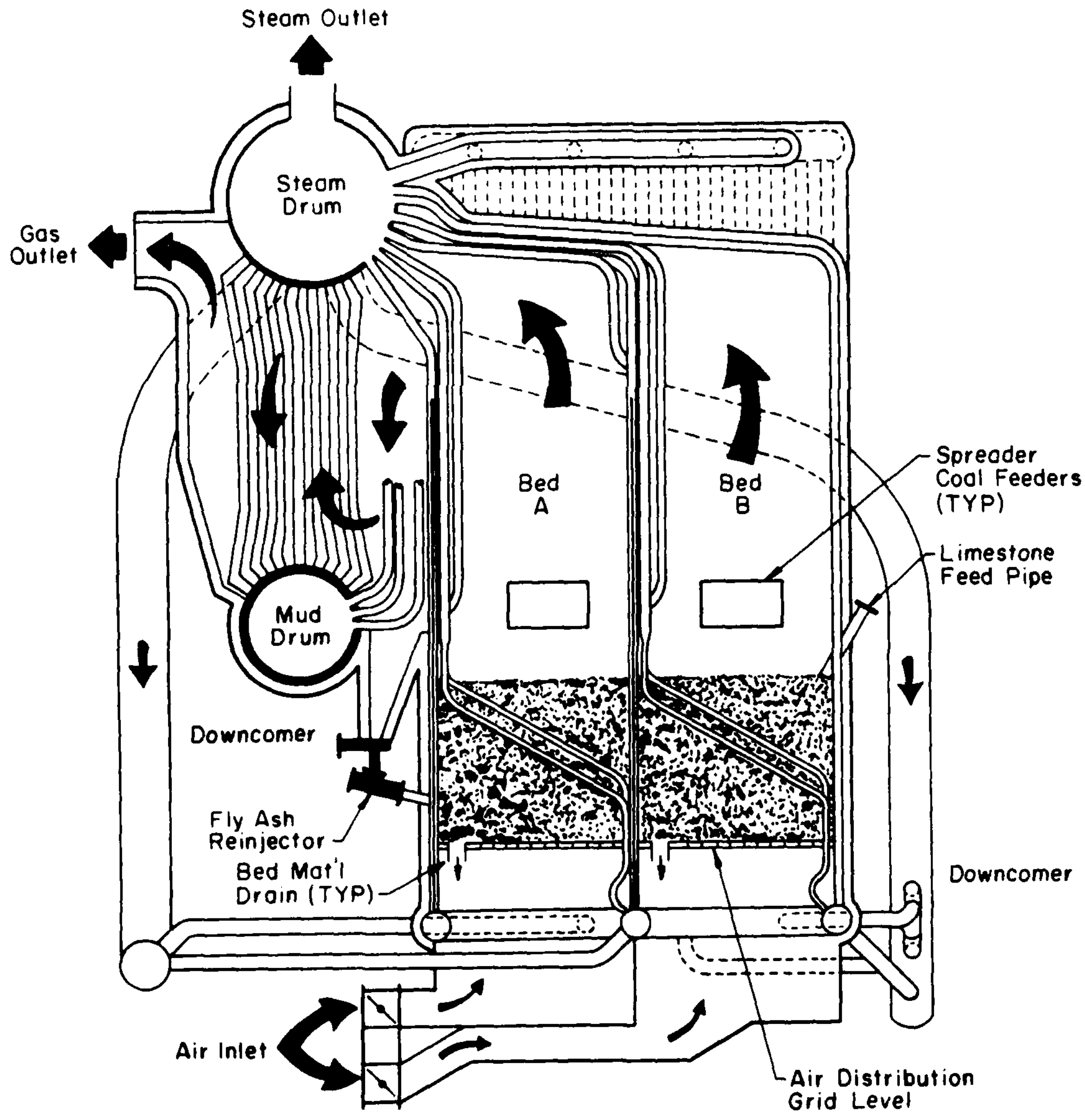

Figure 4. Typical fluidized bed combustor.

Energy Products

Energy Products of Idaho has developed FBC for burning wood waste; this system has been used extensively by the lumber industry, both in CONUS and Japan. Most of these units are used for industrial waste, and the company claims enough units in service to easily establish a track record. The thermal efficiency expectation of 99 percent is totally unrealistic and probably is, in fact, the expected carbon burnout. Among the units studied, this design is one of two that preheat combustion air. The use of a conveyor for the feed system is unique. The manufacturer apparently is very particular about the amount of glass in the waste based on the 1 to 2 percent limit. The primary (or bed) combustion temperature range is wide. The 2000°F secondary, freeboard zone temperature is a strong indication that combustion occurs in this area. The "less than one" operator requirement is unusually low.

Fluidyne

Fluidyne is an FBC designer that subcontracts the actual unit construction. Although none of its FBC designs so far have been burning MSW, this company is interested in burning well defined industrial wastes and currently offers a unit that burns anthracite culm. Fluidyne expects all of its units to be used for burning industrial wastes. A maximum unit size is reported, but no minimum. The expected thermal efficiency is somewhat high, and the maximum waste moisture is very low. The many question marks for the technical data probably reflect a product line which is still under development.

GA Technologies

GA Technologies is actually General Atomic, a company that has been involved in FBC processing of nuclear fuel pellets for many years. This company has joined with Ahlstrom of Finland in a subsidiary company called Pyropower to market externally circulating FBC units for coal combustion. GA apparently is pursuing an independent marketing effort to sell its FBC units for waste incineration. Very few details are known about this equipment except that it is a fast, externally circulating fluidized bed.

Power Recovery Systems

Power Recovery Systems (PRS) plans to produce both gasifiers and boilers, with all units expected to be used for industrial applications. The equipment size range seems narrow. This equipment is sensitive to glass and metal in the waste. The flat plate used for air distribution has been a problem in other designs. The maximum allowable steam pressure seems unusually high at 2400 psig and would be typical of a utility power plant.

Stone Johnston Boiler Co.

Stone Johnston Boiler Co. (originally Johnston Boiler) has a unique system for in-bed circulation and tramp material removal. All units are intended for handling industrial wastes, but not all those listed in Appendix D are burning wastes. The life expectancy for these units is unusually long. Some preheating of combustion air reportedly is done. The lower secondary, freeboard temperature (1400°F) indicates virtually no burning in this area. There are two different designs for firetube and watertube applications.

Thermal Processes

Thermal Processes, Inc. builds an incinerator with heat recovery as an "add-on" waste heat boiler, rather than part of the integral design. Market concentration has been towards industrial waste burning, and the only unit burning MSW (in Japan) reportedly is having feed system problems. This company has very few units in operation on which to form a track record. The size range would be conducive to Army applications, but the expected thermal efficiency is somewhat low. The 20:1 turndown ratio is unrealistic.

York-Shipley

York-Shipley is a major boiler manufacturer that has coupled FBC technology with its heat recovery boilers. This company has experience in burning a wide variety of wastes and offers, as an option, a special tramp material removal system. Most units are targeted for burning industrial waste, with a significant number operating for evaluation purposes. The unit size range would suit the Army's needs. This equipment is claimed to be especially insensitive to waste quality. The refractory used (called Plibrico Plicast Erozist) is reported to be very tough. The "less than one" operator requirement is unusually low. It is not known why an FBC unit would need a scrubber in some cases.

Equipment Comparisons

General Characteristics

These manufacturers have been supplying FBC systems primarily for the industrial consumer in applications for which the waste-fuel stream is well defined. The exception is Dorr Oliver which claims that, of 162 inservice units, 75 percent burn MSW. Although Dorr Oliver has the most inservice units, York-Shipley may be selling more than the other manufacturers at present. Three manufacturers will contract to operate. System availability is claimed to be 90 percent or better. Systems are offered in ranges of 10 to 400 TPD, producing 2500 to 250,000 lb/hr steam with a claimed thermal efficiency of 60 to 85 percent (74 percent average). (Note: the 99 percent Energy Products figure reported is either too optimistic or in error.) Most systems do not preheat. Incinerator life expectancy is from 20 to 30 yr.

Feed Systems

Feed system design for FBC is fairly standard among these manufacturers. A front-end loader conveys raw waste to a shredder and from there the waste may be processed further (glass separation) or go directly to the feed metering bin. There, the shredded waste is fed continuously into the incinerator either by pneumatic feed pipe, screw, or conveyor. The fuel moisture content can be as high as 60 percent (although one company listed a maximum of 6 percent, presumably for conveyance reasons) and the ash content can be as much as 80 percent. Although some manufacturers limit the amount of glass, York-Shipley does not, and restricts metal content only in terms of size. Because of the "flywheel" effect of the heat-retaining sand bed, no supplementary fuel is required to sustain combustion. Feed system outages are claimed to be 5 percent and special feed system maintenance is required for only one of the nine designs.

Combustion Zone

The combustion zone will incinerate nearly 98 percent of the carbon content with a grate thermal release rate of about 0.5 MBtu/hr-sq ft (Johnston reported a rate of 7500

Btu/hr-sq ft which seems low or in error). Underfire air usually is introduced using nozzles or Tuyeres. A primary combustion zone temperature of about 1500°F is maintained by the fuel/air mix; the secondary, freeboard area temperature is the same or slightly higher. Manufacturers use both brick and castable refractories, with the brick having a longer life expectancy of 20 to 30 yr as opposed to the 7- to 10-yr life of castable material. However, York-Shipley offers a castable refractory (Plibrico Plicast Erozist) for which indefinite life is claimed. The incinerator accounts, at most, for about 5 percent downtime.

Boiler

The heat recovery boiler is generally a watertube, but firetube and water-wall configurations also are available. There is wide variation in the heat transfer rate which cannot be explained by the amount of in-bed surface. Soot blowers are provided for freeboard surfaces. The boiler will produce 400 to 950°F steam at pressures from 5 to 900 psig. In general, the manufacturers do not have their blowdown requirements well defined. One company offers an automatic blowdown system, but it is generally done on an as-needed or regularly scheduled basis. Boiler-related outages also are not well defined, but neither are they a frequent occurrence.

Ash System

Ash is handled in a variety of ways. However, there is no clear consensus as to the ratio of bottom (bed) ash to fly ash. With this technology, most of the ash would be expected to be blown out of the incinerator. As mentioned earlier, some manufacturers offer special automatic tramp material removal systems. Ports, letdown pipes, pneumatic, and screw systems also are used. The ash hopper is sealed mechanically and cooled by fluid bed, water-cooled screw, or air. Dorr Oliver uses the fluid-bed cooling method and recycles the ash wastewater. In general, this technology presents no ash wastewater problem. The ash-handling subsystem accounts for less than 5 percent downtime.

Controls

Control systems are almost always automatic, but semiautomatic and manual systems are available. The controls function in response to steam demand and, in most cases, control is achieved by varying the firing rate. The firing rate, in turn, is controlled through bed temperature and O_2 concentration. When O_2 is monitored, the sensing equipment can be located in a variety of areas, including the boiler exit, stack, and freeboard area. Fans usually are controlled by dampers. The turndown ratio is approximately 2:1 to 3:1. Only one operator is needed at the control panel and little, if any, downtime is attributed to the control system.

Environmental Aspects

Environmental quality is maintained by including particulate control systems, in the form of multiclones and baghouses, as standard equipment. These measures are necessary because of the high output dust loading (1 to 3 gr/SCF). Allowable pollutants vary from state to state, but generally, particulate count can be controlled to about 0.03 gr/SCF. Opacity is kept at 10 percent (0.5 Ringleman) or less. Oxides of nitrogen are inherently low at about 100 to 130 ppm. Chloride and sulfide emissions for standard

operation also are very low. Ash water pollution is not a problem for most FBC systems because water is not used directly for cooling; the few units that do use water for ash handling recycle the water. Other pollution control systems can be included based on the user's needs.

Operation

Operation of the typical FBC system requires an operator and a laborer for each of three 8-hr shifts/day, 7 days/week. A mechanic is generally on call or sometimes on full duty 1 shift/day.

7 SUMMARY OF FINDINGS

The data in Appendices A through D were summarized and averaged to compare the different technologies without regard to specific manufacturers. The results are in Appendix E. A single number or comment in these tables represents the average of the findings for manufacturers of that technology. Two numbers separated by a hyphen indicate the range of values found. An indication of range followed by a slash and a single number reveals the average of that range for most manufacturers. In a few cases, values that were unusually large or small were not considered to be representative. In other cases, specific information could not be entered because of the variability in information or because information was available on too few manufacturers to evaluate.

Besides the manufacturers listed in Chapters 2 through 5, it was discovered that Energy Resources Company (ERCO), Envirotech Corp., Air-Preheat Co., CICO, and Neptune Nichols are no longer producing equipment to burn solid wastes. In addition, although they have been credited with waste-to-energy projects, Bigelow Co., Cleaver Brooks (excess-air units), and Zurn Industries have produced only the boilers, with the actual combustion equipment manufactured by others. A few other companies have undergone restructuring and name changes over the past several years; Appendix F lists manufacturers, addresses, telephone numbers, and a point of contact for more information about products discussed in this report.

General Characteristics

In all technologies, most units have been sold for industrial use. This finding probably is due to the ease of burning well defined, homogeneous waste streams and the problems associated with landfilling many industrial wastes. All technologies have a large number of units operating which can be observed first-hand. However, not all manufacturers have enough units operating to evaluate their specific design. Starved-air and rotary kiln technologies apparently sell the largest number of units each year. The starved-air systems have the shortest projected life expectancies.

All technologies reportedly are available in very small units--less than 10 tons/day. However, small units other than starved-air systems have not been as economical due to the additional pollution control equipment they have been required to have. Rotary kiln and FBC units report the highest average thermal efficiency; the value obtained for excess-air grate systems is lower than might be generally expected. Not all manufacturers preheat the combustion air for starved-air and FBC units, whereas this is common practice for rotary kiln and excess-air grate systems. Preheating the combustion air provides a significant improvement in thermal efficiency, but the extra expense may not be justified in all cases. All technologies except FBC claim the ability to burn MSW as well as industrial waste.

Feed Systems

There is no consensus among manufacturers as to the recommended waste-loading system. Smaller plants usually will use a front-end loader while the larger ones will be able to justify a pit-and-clamshell crane. The size at which one method is preferred over the other is not defined clearly.

Rotary kiln and excess-air grate units need the least preprocessing; FBC units require that the waste be processed into a crude form of RDF. All technologies provide continuous feeding. Ram feeders are the most common charging system, but other types also are used. Almost all technologies expect outages related to the feed system to be 1 to 5 percent.

The maximum allowable moisture is approximately 50 percent for most cases, but FBC has been known to burn wastes in the form of slurries. Rotary kiln units apparently are less sensitive to the other waste characteristics than are the other technologies. Starved-air units may need special lubrication, but the other technologies generally do not need special maintenance for the feed system.

Within the starved-air category, the need for supplemental fuel is highly variable, with some designs needing virtually none. The other technologies generally need no supplemental fuel once the waste is ignited. Rotary kiln systems may need some supplemental fuel when burning an extremely difficult waste (e.g., high moisture content or low volatility).

Combustion Zone

Each technology uses a different method of agitating the waste to promote complete combustion. In addition, various methods of introducing underfire air are used to aid combustion except for rotary kiln units, which usually depend on the waste mixing process for contact with combustion air.

None of the manufacturers surveyed have paid much attention to the grate heat release rate, which could be important in predicting the burning material's temperature and tendency to slag. Carbon burnup is fairly high in each case at 93 to 98 percent. There is considerable variation in primary combustion zone temperatures, with the starved-air and FBC units having the lowest values. These low temperatures minimize NO_x production. Air and feed rate are cited in almost every case as the primary means of controlling combustion temperature. Except for starved-air units, the secondary zone temperatures are the same or slightly lower than primary zone temperatures. Claimed combustion-related outages were fairly consistent in all cases at 1 to 5 percent.

Refractories show some variation, but castable and brick types are the most widely used. Life expectancy of the refractory varies considerably, and apparently is closely related to mechanical stress. Rotary kiln applications have the shortest projected life.

Boiler

Except for excess-air grate units, both watertube and firetube boilers are used, and soot blowers are available for both types of boilers. Manufacturers have largely ignored the boiler heat transfer rate--a task probably delegated to the subcontract companies that actually produce the boilers.

Steam pressures reportedly can be developed up to 900 psig (possibly higher for excess-air grate units) and temperatures are generally less than 750°F, although FBC can go as high as 950°F. Blowdown and feedwater consumption requirements are not well defined for any of the technologies. Boiler-related outages are claimed to be approximately 1 percent to 5 percent for all cases.

Ash System

Based on information from the manufacturers, the ratio of bottom ash to flyash has not been well defined for any of the technologies. This parameter can be important for proper sizing of the ash and particulate control systems. Starved-air units usually use ram and conveyor systems for ash removal; the other technologies use a variety of methods. FBC uses only mechanical methods to seal the ash hopper, whereas the other technologies use both mechanical and water seals. Ash-system-related outages are claimed to be 1 to 5 percent for all technologies, which does not seem representative of actual experience. FBC does not use water directly to cool its ash, but the other technologies use both spray and quench systems. Both starved-air and FBC units are claimed to produce no ash water.

Controls

Automatic controls usually are available. All technologies, except for rotary kiln, claim the ability to respond to steam demand, usually through bypassing the gases around the boiler. All technologies use temperature to control the firing rate. Starved-air and rotary kiln units typically do not provide CO or O_2 monitors, but these devices may be provided with excess-air grate and FBC units. All fans are controlled by dampers rather than speed which is more energy-efficient, but also more capital-intensive. Some unusually large turndown ratios are claimed for starved-air systems, but the other technologies are fairly consistent at 2:1 to 4:1. Some starved-air and rotary kiln units may require two operators, but usually only one is needed for these and the other technologies. Claimed control-related outages are especially low for starved-air and rotary kiln systems.

Environmental Aspects

Starved-air units smaller than 50 ton/day usually do not need air pollution control equipment at this time, but limits on hydrochloric acid emissions are being considered by several states which would mandate these devices. Controlled particulate emissions from the other technologies are normally much less than the uncontrolled starved-air emissions. "Typical" NO_x and hydrochloric acid emissions are not well defined nor is ash water solids content for rotary kiln units. No ash water production is claimed with starved-air and FBC systems. Other pollutants in the ash water, such as heavy metals, apparently have not been investigated. Scrubbers are sometimes used for special needs such as acid gas control.

Operation

Each technology usually requires only one operator, but starved-air and rotary kiln units may need two. A mechanic and/or a laborer also may be needed. Starved-air technology has the potential of being the most labor-intensive. All technologies are basically operable 3 shifts/day, 7 days/week.

8 CONCLUSION

The state of the art in HRI equipment has been reviewed by collecting technical data from various manufacturers and evaluating these systems with respect to Army applications. To compare products, the systems were first analyzed by operational concept (i.e., starved-air, excess-air grate, fluidized bed combustion, and rotary kiln technologies); then, overall properties were summarized among the technologies.

Many different products are available in a wide range of sizes. In particular, it was found that HRI equipment in the small sizes of interest to the Army is being marketed for technologies other than starved-air. The Army traditionally has chosen starved-air units because, in system sizes below 50 TPD, they required no additional equipment for pollution control. The other technologies require particulate control as a minimum. With stricter pollution control legislation either enacted or anticipated, starved-air technology may lose its economic advantage.

In states that have adopted acid gas control laws, Army HRI plants with units sized at 20 TPD or larger probably will be starved-air or excess-air grate; economics will be the deciding factor. For installations not located in states with this legislation, modular starved-air systems no doubt will remain the best choice.

Rotary kiln and FBC technologies also can be expected to have definite, yet limited, applications. Rotary kiln units offer the advantage of burning difficult wastes such as sludges and other very wet materials. FBC systems can be used for highly homogeneous wastes that may be hazardous due to acidity or potentially toxic agents. The FBC units can burn liquids and sludges in addition to solids, and can burn several fuels simultaneously.

Brief guidance has been provided for planning an HRI project. It must be stressed that each installation would need to conduct a thorough evaluation for all systems under consideration to assess the technology, economics, and environmental impact. References containing more complete instructions have been cited.

In terms of revising CEGS 11171 to include this information, it has been found that several characteristics are common to all technologies and could be incorporated easily into the CEGS. However, many other properties are unique to the individual systems, so that flexibility will have to be allowed.

APPENDIX A:

STARVED-AIR UNITS

Table A1

Starved-Air Units: General Characteristics

Item	Atlas	Brulé	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
Type of unit*	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved	Mod. starved
No. units sold/yr	-	-	1	-	50	-	200-300	10-15	35	2	10-15	-	5-10	-
Percent industrial vs municipal	-	-	99	-	99	-	80	90	100	-	90	-	100	-
Company contracts to operate units?	-	-	No	-	No	-	Yes	Yes	No	No	Yes	-	No	No
No. units in service now	60+	-	-	-	1000	-	2000+	100	200	11	2	-	3	-
Expected life of unit (yr)	-	-	5-15	-	10	-	15-20	20	12	-	10-15	-	10-15	10
Avg availability (%) (i.e., not down for repair, maintenance)	-	-	90-95	-	90	-	95	85	95	-	90	-	90+	-
Size range per unit (TPD in 3 shifts)	12-24	24-72	5-40	25-48	2-31	2-37	5-100	10-75	9-43	3.6-100	15-36	21-64	2.4-24	13-24
Steam generation range (lb/hr)	-	9K-	Varies	-	1K-10K	-	1.1K-50K	2K-15K	1K-13K	-	0-10K	5.7-17K	2K-7.5K	-
Expected thermal efficiency (%)	-	-	60	40	55-70	55	60-65	63	55.7	-	62-65	74	56+	55
Required fans provided with units as standard?	Yes	-	Yes	-	Yes	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Method of preheating combustion air	-	-	None	-	Skin heat	Stack plenum	Heat exch.	Heat shrouds	In design	-	Air jacket	-	None	None
Type of waste fuel**	Ind.	-	MSW & ind.	-	-	All types	MSW &. ind.	MSW & ind.	-	-	-	-	-	-

*Modular, starved, waterwall, etc.
**Municipal solid waste (MSW), industrial, etc.

Table A2

Starved-Air Units: Feed System

Item	Atlas	Brule	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
Recommended waste retrieval system*	-	-	Front loader	-	Cart dumper	—	Front loader	All	Carts	Site spec.	Front loader	-	Optional	Clam-shell
Type of pre-processing required (if any)	-	-	Remove bulky	-	Glass removal	-	Remove bulky	None	None	Remove bulky	None	-	Remove non.	Salvage
Type of feeding**	-	-	Cont.	-	Both	-	Cont.	Both	Both	-	Both	Cont.	-	-
Type of feed system***	Ram & conv.	Ram	Ram	Ram	Ram	Ram	Ram	Ram	Ram	Silo & feeder	Ram & conv.	Ram	Ram	Ram
Expected feed system outage frequency (%)	-	-	1-2	-	Negligible	-	<1	5	2	-	?	-	5%	-
Max. allowable moisture content (%)	-	-	?	-	25	-	45	None	40	-	30	-	25	70
Max. allowable ash content (%)	-	-	?	-	15	-	40 (dry)	?	20	-	-	-	10	10
Max. allowable glass content (%)	-	-	?	-	0.05	?	No limit	15	5	-	-	-	<5	5
Max. allowable metal content (%)	-	-	?	-	1	-	No limit	20	5	-	-	-	≤5	5
Feed system special maintenance	-	-	None	-	Lubrication	-	None	None	None	-	Lubrication	-	Water spray	Lubrication
Amount of supplemental fuel	-	-	<500 KBtu	-	1.2 MBtu/ton	-	None to sustain	200K Btu	560 cu ft/ton	-	0.2 Mbtu/ton	0.2 MBtu/ton	200 gallon/ton	21 gallon/ton

*Clamshell, front loader, etc.
**Continuous vs batch.
***Ram, conveyor, etc.

Table A3

Starved-Air Units: Combustion Zone and Boiler

Item	Atlas	Brulé	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
Type of combustion grate*	-	-	Int. ram	Recip. grate	Int. ram	Int. ram	Int. ram	Int. ram	Flat	-	Moving hearth	Incl. vib.	None	Inclined
Method of introducing underfire air	Ports	-	None	Grates	Ports	Ports	Ram air tubes	Hearth plenum	Side nozzles	-	Air orifices	Blowers	Air tubes	Blowers
Design heat release rate (Btu/hr-sq ft)	-	-	10,000	-	-	-	-	10,000	85,000	-	<20,000	83-109K	180,000	2500
Carbon burnup (%)	-	-	92	-	99	-	94	96	97	95	95-99	95	99+	90
Primary combustion zone temp. ($^{\circ}F$)	-	-	1400	1800	1200	1500	1200-1400	1700	1400-1600	1400-2000	1000-1100	1650	1200-1600	1400
Method of maintaining temp.	-	-	Feed rate	-	Burner	Air & fuel.	Air supply	Air & steam	Air/gas mod.	-	Air	Air	Air & water	-
Secondary combustion zone temp. ($^{\circ}F$)	-	-	1800	1800	1800-2000	1800	1600-2200	1800-2000	1800	1800-2100	1600-2000	1900	1600-1800	1500
Expected combustion-related outage frequency (%)	-	-	1-2	-	<1	-	0	5	1	-	?	-	<5	-
Type of refractory	-	-	Brick & gunnite	-	Cast. & brick	-	Cast. & brick	Cast. & brick	Castable	Brick	Ref. & brick	-	Castable	PCE 32-1/2
Expected life of refractory (yr)	-	-	2-10	-	5-10	-	7-10	5-8	7	-	10-15	-	3-5	5
Type of boiler**	Fire-tube	Both	Both	Both	Fire-tube	Both	Both	Both	Fire-tube	Fire-tube	Fire-tube	Both	Fire-tube	Fire-tube
Heat transfer rate (Btu/hr-sq ft)	-	-	7.4	-	6-8	-	-	-	5770	-	-	-	?	4000
Soot cleaning method	-	-	Brush	-	Blower (opt)	-	Air	Blowers	Manual	-	Brush	-	Blowers	Manual
Steam temp. ($^{\circ}F$)	-	-	<487 Sat.	-	212-450	-	650+	350-600	339-353	-	Saturated	406	-	360
Steam pressure range (psig)	11-80	150	<600	130-200	13-150	15-200	600+	50-600	100-125	-	15-150	250	15-350	150

Table A3 (Cont'd)

Item	Atlas	Brule	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
Feedwater consumed (gal/ton) (full condensate return)	-	-	2%	-	Negligible	-	-	-	?	-	Varies	-	-	-
Type and frequency of blowdown***	-	-	Either	-	Either 1/day	-	Auto./man.	Both	?	-	Either	-	Either	Manual
Expected boiler outage frequency (%)	-	-	1-2	-	<1	-	0-5	2	0	-	-	-	-	-

*Inclined, rotary, FB, etc.
**Firetube or watertube.
***Manual vs automatic.

Table A4

Starved-Air Units: Ash System

Item	Atlas	Brule	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
Ratio bottom ash/flyash	-	-	95-99%	-	?	-	?	98%	100:1	-	?	-	35000:1	-
Type of bottom ash removal system	Manual & auto.	-	Ram & conv.	Conveyor	Ram & conv.	Conv.	Ram & conveyor	Conv. or backhoe	Conv. or	Screw auger	-	Grate clam	Drag conv.	Ram
Method of sealing ash hopper draft*	Mech.	Both	Mech.	Water	Both	Both	Water	Water	Water	-	Mechanical	Water	Slide gate	Mechanical
Expected ash system outage frequency (%)	-	-	1-2	-	<1	-	0-2	5	5	-	?	0	-	-
Type of bottom ash cooling	-	-	Spray	Quench	Spray/quench	Quench	Quench	Quench	Quench	-	Spray	Quench	Spray	-
Ash wastewater produced (gal/ton) (if applicable)	-	-	0	-	None	-	?	N/A	None	None	None	-	-	-

*Water, mechanical, etc.

Table A5

Starved-Air Units: Controls

Item	Atlas	Brulé	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
Control system*	Semi.	-	Semi.	-	Auto.	-	Auto.	Auto.	Semi. auto.	Auto.	Auto.	Auto.	Auto. manual	Auto.
Response to steam demand (yes/no)	Yes	-	Optional	-	Yes	-	Yes	Yes	No	-	Yes	-	Yes	No
Method of steam output control**	Bypass	-	Firing	-	Bypass	Bypass	Fire/ bypass	Bypass	Bypass	-	All	-	Bypass	Bypass
Origin of firing rate control signal***	-	-	Timer	-	Temp. & pressure	-	Temp.	Temp.	Draft	-	Temp.	-	Temp.	Temp.
Type/location of CO or O_2 monitors (if any)	-	-	None	-	None	-	Boiler exit	Stack	None	-	None	-	None	As required
Method of fan control	Dampers	-	Dampers	-	Dampers	-	Dampers	Dampers	Dampers	-	Dampers	Dampers	-	Dampers
Turndown ratio of unit	-	-	1:20	-	2:1	-	2:1	-	4:1	-	10:1	-	10:1	10:1
Number of operators required	-	-	3/shift	2/shift	1	1/shift	Varies	1/shift	1/shift	-	1	-	2/shift	1
Expected control outage frequency (%)	-	-	1-2	-	<1	-	0	1	1	-	?	-	0	-

*Automatic, semiautomatic, or manual.
**Firing, fans, or bypass.
***CO, O_2, temperature.

Table A6

Starved-Air Units: Environmental Aspects

Item	Atlas	Brule	Burn-Zol	Air	Clear Brooks	Cleaver Comtro	Consumat	ECP	Simonds	Stock	Tech	Therm-UIP Eng	US Smelt	Wash & Grange
Pollution control devices supplied as standard	None	Cyclone	None	-	None	None	None	As needed	None	Hot cyclone	None	Set. chamber & cyclone	None	Scrubber
Expected uncontrolled emissions:														
Particulates	-	-	<0.08 gr/ DSCF	-	<0.1 gr/ DSCF	-	1.8 lb/ ton	0.13 gr/ DSCF	0.08 gr/ DSCF	-	<0.1 gr/ DSCF	-	Varies	-
Nitrogen oxides	-	-	-	-	Negligible	-	1.07 lb/ ton	Varies	-	-	-	-	Varies	-
Other measured pollutants (Cl)	-	-	-	-	Negligible	-	-	Varies	-	-	50 ppm	-	Varies	-
Opacity	-	-	-	-	Clear	-	-	0-20%	5%	-	0	-	Varies	-
Expected controlled emissions:														
Particulates	As required	-	-	-	NA	-	0. 5 lb/ ton	0.04 gr/ DSCF	0.03 gr/ DSCF	-	<0.1 gr/ SCF	-	<0.1 gr/ SCF	-
Nitrogen oxides	As required	-	-	-	NA	-	1.07 lb/ ton	Varies	-	-	-	-	-	-
Other measured pollutants (Cl)	As required	-	-	-	NA	-	-	Varies	-	-	50 PPM	-	-	-
Opacity	As required	-	-	-	Clear	-	-	0-20%	-	-	0	-	-	-
Ash-water solids content	-	-	N/A	-	NA	-	30-40%	N/A	?	-	0	-	N/A	-
Other pollutants in the ash water	-	-	0	-	?	-	-	?	-	-	0	-	-	-
Pollution control devices for special needs	-	Scrubber	Yes	-	Scrubber	Scrubber	Yes	Baghouse	-	-	Washer	-	As required	Wet scrubber

Table A7

Starved-Air Units: Operation

Item	Atlas	Brulé	Burn-Zol	Clear Air	Cleaver Brooks	Comtro	Consumat	ECP	Simonds	Stock	Therm-Tech	UIP Eng	US Smelt	Wash & Grange
No. personnel/ shift required:														
Operators	-	-	3	2	1	1	*Varies*	1	1	-	1	-	1	1
Mechanics	-	-	-	-	-	-	-	1	As needed	-	1/4	-	1	0
Laborers	-	-	2	1	1	-	-	0	0	-	-	-	0	0
Designed operating schedule (no. shifts/ no. days/week)	3/6	3/5	3/7	3/6	3/6	3/7	3/7	3/7	3/7	3/7	3/6	-	3/5	-

APPENDIX B:

ROTARY KILN UNITS

Table B1

Rotary Kiln Units: General Characteristics

Item	C-E Raymond	Giery	Industrionics*	O'Connor	Therm-All	Trofe
Type of units**	Rotary kiln	Basket	Rotary kiln	Rotary kiln	Rotary kiln	Rotary
No. units sold/yr	3-4	--	7	3	5-10	0
Percent industrial vs municipal	100	--	50	1	100	0
Company contracts to operate units?	No	--	No	Yes	Yes	Yes
No. units in service now	20	--	30	8+	5	1
Expected life of unit (yr)	20	--	--	30	10	20
Avg. availability (%) (i.e., not down for repair, maintenance)	90	--	--	96+	85	80
Size range per unit (TPD in 3 shifts)	13-320	--	2.7-160	50-300	9-50	50-250
Steam generation range (lb/hr)	--	--	720-43000	14.4K-72K	3K-15K	15K-72K
Expected thermal efficiency (%)	70	--	65-75	70+	50-65	70
Required fans provided with units as standard?	Yes	--	Yes	Yes	Yes	Yes
Method of preheating combustion air	Varies	--	Shroud and ash	Tube air heat	Recuperator	None
Type of waste fuel ***	All	--	MSW & ind.	MSW	Ind. solid & sludges	All

*Controlled air.
**Modular, starved, waterwall, etc.
***Municipal solid waste (MSW), industrial, etc.

Table B2

Rotary Kiln Units: Feed System

Item	C-E Raymond	Industrionics*	O'Connor	Therm-All	Trote
Recommended waste retrieval system**	Varies	--	Any	Custom design	Conveyor
Type of preprocessing required (if any)	Some shredding	None	None	Varies	None
Type of feeding***	Both	Continuous	Continuous	Continous	Batch
Type of feed system+	Varies	Auger or pump	Dual ram	Custom design	Pulse
Expected feed system outage frequency (%)	--	--	0	15	2
Max. allowable moisture content (%)	100	--	50	No limit	50
Max. allowable ash content (%)	100	--	--	No limit	No limit
Max. allowable glass content (%)	Temp.-depend.	--	--	No limit	20
Max. allowable metal content (%)	100	--	--	No limit	20
Feed system special maintenance	None	--	None	None	None
Amount of supplemental fuel	Varies	None	None	Varies	Usually none

*Controlled air.
**Clamshell, front loader, etc.
***Continuous or batch.
+Ram, conveyor, etc.

Table B3

Rotary Kiln Units: Combustion Zone and Boiler

Item	C-E Raymond	Industrionics*	O'Connor	Therm-All	Trofe
Type of combustion grate**	Rotary	Rotary	Rotary	Rotary	Oscil. bed
Method of introducing underfire air	NA	None	Air holes	None	Radial inject.
Design heat release rate (Btu/hr-sq ft)	15K-60K	-	-	15K-17K	-
Carbon burnup (%)	Varies	98	93	96	99.99
Primary combustion zone temp. (^{O}F)	1400-2800	1750	2600-2900	Varies	2200
Method of maintaining temp.	Air & burner	--	Multiple	Feed rate	Feed rate
Secondary combustion zone temp. (^{O}F)	1800-2800	2200-2400	1200-1800	1600-1800	2500
Expected combustion-related outage frequency (%)	5	--	None	?	5
Type of refractory	Varies	--	None	Custom design	70% Al_2O_2
Expected life of refractory (yr)	0.5.-10	--	NA	3-5	1-2
Type of boiler***	Both	Both	Watertube	Both	Watertube
Heat transfer rate (Btu/hr-sq ft)	Varies	--	--	Custom design	Varies
Soot cleaning method	Varies	--	Blowers	Custom design	Blowers
Steam temp. range (°F)	<500	--	<750	Custom design	As required
Steam pressure range (psig)	<500	0-225	250-800	Custom design	As required
Feedwater consumed (gal/ton) (full condensate return)	5%	--	0	Custom design	Varies
Type/and frequency of blowdown (manual vs auto.)	Varies	--	Either	--	Auto.
Expected boiler outage frequency (%)	5	--	0	?	5

*Controlled air.
**Inclined, Rotary, FB, etc.
***Firetube or watertube.

Table B4

Rotary Kiln Units: Ash System

Item	C-E Raymond	Industrionics*	O'Connor	Therm-All	Trofe
Ratio bottom ash: flyash	--	--	Variable	?	95
Type of bottom ash removal system	Wet & dry	—	Conveyor	Wet & dry	Quench
Method of sealing ash hopper draft**	Both	--	Mech./water	Mechanical	Water
Expected ash system outage frequency (%)	5	--	1/month	?	1
Type of bottom ash cooling	Air & water	Air	Quench	Water mist	Water
Ash waste-water produced, (gal/ton) (if applicable)	Varies	0	--	?	--

*Controlled air.
**Water, mechanical, etc.

Table B5

Rotary Kiln Units: Controls

Item	C-E Raymond	Industrionics*	O'Connor	Therm-All	Trofe
Control System	Auto.	Auto. or manual	Auto.	Custom design	Auto.
Response to steam demand?	No	--	Yes	No	No
Method of controlling steam output**	None	--	Multiple	Firing rate	Blowoff
Origin of firing rate control signal***	All	Sec. temp.	Steam flow	Custom design	Temp.
Type and location of CO or O_2 monitors (if any)	--	--	O_2 Blr; outlet	If required	Multiple
Method of fan control	Dampers	--	Revs./min	Dampers	Dampers
Turndown ratio	Infinite	--	2:1	3:1	4:1
No. operators/shift required	1.5	--	Variable	1-2	2
Expected control outage frequency (%)	1	--	0	?	2

*Controlled air.
**Firing, fans, bypass, etc.
***CO, O_2, temperature.

Table B6

Rotary Kiln Units: Environmental Aspects

Item	C-E Raymond	Industrionics*	O'Connor	Therm-All	Trofe
Polution control devices supplied as standard	Yes	Optional baghouse and scrubber	Baghouse, ESP dry scrubber	Baghouse dry scrubber	Yes
Expected uncontrolled emissions:					
Particulates	0.08 gr/SCF	0.087 gr/DSCF	Variable	0.1-0.5 gr/DSCF	0.03 gr/SCF
Nitrogen oxides	As required	--	Variable	50-100 ppm	0
Other measured pollutants (Cl)	Negligible	--	Variable	HCl 40-100 ppm	0
Opacity (%)	30	--	Variable	0	0
Expected controlled emissions:					
Particulates	0.01 gr/SCF	--	As required	0.005 gr/DSCF	0.03 gr/SCF
Nitrogen oxides	Varies	--	As required	50-100 ppm	0
Other measured pollutants (Cl)	5000 ppm	--	As required	HCl 10-40 ppm	0
Opacity	--	--	As required	0	0
Ash-water solids contents	As required	None	?	90-95%	30%
Other pollutants in the ash water	As required	--	?	?	?
Pollution control devices for special needs	Yes	O_2,CO,CO_2 monitors	As required	--	Yes

*Controlled air.

Table B7

Rotary Kiln Units: Operation

Item	C-E Raymond	Industrionics*	O'Connor	Therm-All	Trofe
No. personnel/shift required:					
Operators	1.5	--	Variable	Variable	2
Mechanics	1/3	--	Variable	Variable	1
Laborers	Varies	--	Variable	Variable	2
Designed operating schedule (no). shift/no. days/week)	3/6.5	3/5	As required	3/7	3/7

*Controlled air.

APPENDIX C:

EXCESS-AIR GRATE UNITS

Table C1

Excess-Air Grate Units: General Characteristics

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
Type of units*	Modular WW	Modular WW	Modular WW	WW	Modular
No. units sold/yr	--	--	--	8	11
Percent industrial vs municipal	85	--	10	80	98
Company contracts to operate units?	--	--	No	Yes	Yes
No. units in service now	18	5	25	1455	100
Expected life of unit (yr)	20	--	30-40	30	20+
Avg. abailability (%) (i.e., not down for maintenance, repair)	90	--	>80	95	100
Size range per unit (TPD in 3 shifts)	21-150	15-120	50-1250	1-300	24-840
Steam generation range (lb/hr)	5.6K-40K	--	10K-250K	Variable	<140K
Expected thermal efficiency (%)	70	--	54.5-68	30-35	60
Required fans provided with units as std?	Yes	--	Yes	Yes	Yes
Method of preheating combustion air	Direct F.G.	None	None	Heat exch.	Heat sink
Type of waste fuel**	MSW & ind	MSW	MSW & ind.	MSW & ind.	MSW & wood

*WW = waterwall.
**Municipal solid waste (MSW), industrial, etc.

Table C2

Excess-Air Grate Units: Feed System

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
Recommended waste retrieval system	Front loader	Loader or crane	Clamshell	As required	Front loader
Type of preprocessing required (if any)	Remove bulky waste	--	Remove bulky waste	None	None
Type of feeding*	Continuous	Continuous	Continuous	As required	Both
Type of feed system	Ram	Conveyor or ram	Ram	Ram	Conveyor or ram
Expected feed system outage frequency (%)	1	--	<5	5	3
Max. allowable moisture content (%)	30-40	--	60	35	60
Max. allowable ash content (%)	40	--	25	27	40
Max. allowable glass content (%)	30	--	--	10-15	Normal
Max. allowable metal content (%)	30	--	--	8-10	Normal
Feed system special maintenance**	None	--	Lubrication	None	--
Amount of supplemental fuel	None for <4000 Btu	None for <3000 Btu	None to sustain	None	None

*Continuous or batch.
**Air lance, high-temperature lubrication, etc.

Table C3

Excess-Air Grate Units: Combustion Zone and Boiler

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
Type of combustion grate*	Pulse hearth	Inc. recip.	Inc. recip.	Stoker	V-hearth
Method of introducing underfire air	Air jet	Orifices	Plenum	Grates	Forced
Design heat release rate (Btu/hr-sq ft)	100,000	--	225K-300K	325,000	--
Carbon burnup (%)	95	95	96-97	96-97	98
Primary combustion zone temp. (^{O}F)	1600	1800	2200	1600-1800	1800
Method of maintaining temp.	Air limit	Air	--	Air control	Burn tires
Secondary combustion zone temp. (^{O}F)	2000	1800	None	None	1700
Expected combustion-related outage frequency	1 day/3 wk	--	None	None	<10%
Type of refractory	Plastic, cast	Fire brick	Silicon carbide	Fire brick	Olivine
Expected life of refractory (yr)	2-20	--	--	10-15	9+
Type of boiler**	Both	Both	--	Both	Both
Heat transfer rate (Btu/hr-sq ft)	--	--	--	--	--
Soot cleaning method	Steam or air	—	—	—	—
Steam temp. range (^{O}F)	Sat. or super	--	--	--	--
Steam pressure range (psig)	200-625	--	--	--	--
Feedwater consumed (gal/ton) (full condensate return)	?	--	--	--	--
Type/frequency of blowdown (manual vs auto)	As required	--	--	--	--
Expected boiler outage frequency	1 day/mo.	--	--	--	--

*Inclined, Rotary, FB, etc.
**Firetube and wastetube.

Table C4

Excess-Air Grate Units: Ash System

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
Ratio bottom ash:flyash	--	--	90:10	Variable	--
Type of bottom ash removal system	Backhoe	Drag conveyor	Mechanical	Drag conveyor	Ram
Method of sealing ash hopper draft*	Water	--	Mechanical	Water	Air pressure
Expected ash system outage frequency	3 day/yr	--	--	5%	None
Type of bottom ash cooling	Water	Quench	Water spray	Water	Water spray
Ash waste-water produced (gal/ton) (if applicable)	--	--	--	0.2-0.4	--

*Water, mechanical, etc.

Table C5

Excess Air-Grate Units: Controls

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
Control system*	Auto. or semi.	Auto.	--	Auto.	Manual & semi.
Response to steam demand?	Yes	--	--	Yes	--
Method of controlling steam output	Feed rate	--	--	Firing & bypass	Bypass
Origin of firing rate control signal**	Temp.	Temp.	--	As required	--
Type and location of CO or O_2 monitors (if any)	None	--	--	Stack inlet	--
Method of controlling fans***	Dampers	--	--	Dampers	Dampers
Turndown ratio of unit	4:1	--	--	3.3:1	75%
No. operators required	1	--	--	Varies	1/shift
Expected control outage frequency	<3 days/yr	--	--	5%	?

*Automatic, semiautomatic, or manual.
**CO, O_2, or temperture.
***Dampers, venting, speed, etc.

Table C6

Excess-Air Grate Units: Environmental Aspects

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
Pollution control devices supplied as std.	Electrogravel filter	ESP	None	ESP or baghouse	Gravel scrubber
Expected uncontrolled emissions:					
Particulates	<0.41 gr/SCF	--	--	1.1 gr/DSCF	--
Nitrogen oxides	35 ppm	--	--	Trace	--
Other measured pollutants (Cl)	HCl & CO <10 ppm	--	--	150-200 ppm	--
Opacity (%)	<20	--	--	#1-1.5 (Ringleman)	
Expected controlled emissions:					
Particulates	<0.01 gr/SCF	--	--	0.03-0.05 gr/DSCF	0.02 gr/DSCF
Nitrogen oxides (ppm)	<35 ppm	--	--	Trace	76.6 ppm
Other measured pollutants (Cl)	--	--	--	150-200 ppm	52 ppm
Opacity (%)	<3	--	--	0	Clear
Ash-water solids content (%)	50	--	--	Varies	NA
Other pollutants in the ash water	--	--	--	?	NA
Pollution control devices for special needs	Scubber-HCl	--	--	As required	--

Table C7

Excess-Air Grate Units: Operation

Item	Basic Env.	Clear Air	Detroit Stoker	Morse Boulger	Olivine
No. personnel/shift required:					
Operators	1	--	--	--	--
Mechanics	1	--	--	--	--
Laborers	--	--	--	--	--
Designed operating schedule (no. shifts/no. days/week)	3/7	--	--	3/7	--

APPENDIX D:

FLUIDIZED BED COMBUSTION UNITS

Table D1

Fluidized Bed Combustion Units: General Characteristics

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
Type of units	FBC	FBC	FBC	FBC	CFBC	FBC	FBC	FBC	FBC
No. units sold/yr	0	-	4	1	-	1	4	1	4-8
Percent industrial vs municipal	All MSW	24	90	100	-	100	100	75	95
Company contracts to operate units ?	No	No	Yes	Yes	-	Yes	No	No	No
No. units in service now	1	162	48	1	-	4	24	4	30+
Expected life of unit (yr)	?	20-30	30+	25	-	20	25-50	20	15-20
Avg. availability (%) (i.e., not down for maintenance, repair)	?	99+	96-98	90	-	90	90+	95	90-95
Size range per unit (TPD in 3 shifts)	10-40	95-400	25-350	267 Max.	-	51-157	27-187	12-350	13-400
Steam generation range (lb/hr)	6000	10K-200K	10K-250K	100,000	-	13K-85K	10K-70K	2.5K-75K	5K-100K
Expected thermal efficiency (%)	75	60-80	99	80+	-	60-85	80+	65	-
Required fans provided as std.	Yes	Yes	Yes	Yes	-	Yes	Yes	Yes	Yes
Method of preheating combustion air	None	None	Heat exch.	None	-	None	Convection	None	None
Type of waste fuel*	Coarse RDF	RDF, pulp, or sludge	Ind. & wood	Ind.	Ind.	Ind. & RDF	Ind.	All	MSW, ind. biomass

*RDF = refuse-derived fuel; ind. = industrial; MSW = municipal solid waste.

Table D2

Fluidized Bed Combustion Units: Feed System

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
Recommended waste retrieval system	None	Front loader	Front loader	None	-	Front loader	None	Front loader	Front loader or conveyor
Type of preprocessing required (if any)	Shred & class.	Shred or pulp	Shred	Shred & class	-	Shred/ screen	Shred & class	Shred	Shred & class
Type of feeding*	Contin-uous	Contin-uous	Contin-uous	Contin-uous	-	Contin-uous	Contin-uous	Contin-uous	Contin-uous
Type of feed system**	Pneu.	Screw/ pneu	Conveyor	Screw/ pneu	—	Screw/ pneu	Screw & conv.	Screw	Conv. or pneu
Expected feed system outage frequency	?	1 hr/wk	2-5%	?	-	1-6/yr	Varies	5%	1-3%
Max. allowable moisture content (%)	50	30-60	60	6	-	20-50	25-50+	60	55
Max. allowable ash content (%)	30	20-30	10	40	-	10-40	50+	No limit	75-80
Max. allowable glass content (%)	As recom.	10	1-2	?	-	Trace	?	20	No limit
Max. allowable metal content (%)	As recom.	5-10	10	?	-	Trace	?	No limit	Size limit
Feed System Special Maintenance***	None	None	None	?	-	Air Lance	None	None	None
Amount of supplemental fuel	None to sustain	None to sustain	None to sustain	None to sustain	None to sustain	None to sustain	None to sustaine	None to sustain	None to sustain

*Continuous or batch.
**Pneu = pneumatic; conv. = conveyor.
***Air Lance, High-Temperature Lubrication, etc.

Table D3

Fluidized Bed Combustion Units: Combustion Zone and Boiler

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
Type of combustion grate*	FB	FB	FB	FB	CFB	FB	FB	FB	FB
Method of introducing underfire air	Tuyeres	Tuyeres	Nozzles	-	-	Dist. plate	Nozzles	Nozzles	Nozzles
Design heat release rate (Btu/hr-sq ft)	458,333	200,000	400,000	?	-	0.8-2.8 MBtu	7500	350,000	400K-800K
Carbon burnup (%)	99+	98.5	99+	99	-	96+	95+	95	-
Primary combustion zone temp. (°F)	1400	1500	1200-1800	1500	1500-1600	1500-1600	1600	1800	1500-1600
Method of maintaining temp.	Fuel feed	Feed air	Fuel & air	Load/ fuel	-	Air & feed	Design/ air	Quench air	Air & height
Secondary combustion zone temp. (°F)	1400	1650-1700	2000	1500	1500-1600	1600-1800	1400	-	1600-1800
Expected combustion-related outage frequency	None	2 hr/wk	1%	5%	-	4-12 days/yr	?	5%	2-3%
Type of refractory	Aluminum silicate	Al_2O_3 Brick	Castable	None	-	Brick & castable	None	Block & castable	Plibrico Erozist
Expected life of refractory (yr)	5-10	20-30	5-7	-	-	10	None	10	Indefinite
Type of boiler**	Watertube	Watertube	Both	Watertube	Watertube	Watertube	Both	Both	Firetube
Heat transfer rate (Btu/hr-sq ft)	45-55	?	-	?	-	0.37-2.1 MBtu	-	7.5-10.7	-
Soot cleaning method	None	Blowers	Steam	Blowers	-	None	Blowers	Blowers	Blowers
Steam temp. range (°F)	486-750	Sat.-750	950 max.	?	-	335-666	413-750 max.	Sat. & sup.	Sat.-700
Steam pressure range (psig)	600	50-650	900 max.	?	-	110-2400	300-850 max.	5-650	450 max
Feedwater consumed (gal/ton) (full condensate return)	?	5%	None	?	-	30	-	-	1%
Type and frequency of blowdown (manual vs auto.)	As required	As required	Automatic	?	-	Man. 1/day	Variable	Either	Man. 1/shift
Expected boiler outage frequency	?	2 hr/wk	<1%	?	-	6 days/yr	?	5%	0

*FB = fluidized bed; CFB = circulating FB.
**Firetube or watertube.

Table D4

Fluidized Bed Combustion Units: Ash System

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
Ratio bottom ash:fly ash	4:1	10-25% bot.	25% bot.	?	-	-	49:1	Variable	Variable
Type of bottom ash removal system	Pneumatic	Underflow	-	Pneumatic	-	Letdown pipe	Screw	Screw	Ports
Method of sealing ash hopper draft*	Mechanical	Mechanical	Mechanical	-	-	Mechanical	Mechanical	Mechanical	Mechanical
Expected ash system outage frequency	?	2 hr/wk	5%	?	-	2-6/yr	?	5%	1%
Type of bottom ash cooling	Cooled screw	Fluid bed	Air cooled	Screw	-	Screw	Screw	Cooled screw	Air
Ash waste-water produced (if applicable)	None	Recycled	None	None	-	None	Variable	Variable	None

*Water, mechanical, etc.

Table D5

Fluidized Bed Combustion Units: Controls

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
Control system*	Auto.	Semi-auto	Auto.	Auto.	Auto.	Auto.	Auto.	Auto.	Semi. or man.
Response to steam demand ?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Method of controlling steam output	Firing rate	Firing rate	Firing	Fuel/air	-	Firing	Air	Feed rate	Firing rate
Origin of firing rate control signal**	Bed temp.	O_2 & *temp.*	*Temp.*	*Bed temp.*	-	O_2	O_2	Steam demand	Temp./O_2
Type and location of CO or O_2 monitors (if any)	Freeboard	Outlet	None	Freeboard	-	Blower exit	Stack	None	Stack
Method of controlling fans***	Dampers	Damper or *speed*	Dampers	-	-	Damper	Dampers	Pressure	Dampers
Turndown ratio of unit	2.5:1	1.7:1	3:1	2:1	-	2-3:1	4:1	20:1	4:1
No. operators required	1	1	<1	2	-	1	Variable	1	1
Expected control outage frequency	?	1 hr/wk	1%	?	-	4-6/yr	?	5%	2%

*Auto. = Automatic; semi. = semiautomatic; man. = manual.
**CO, O_2, temperature.
***Dampers, venting, speed, etc.

Table D6

Fluidized Bed Combustion Units: Environmental Aspects

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
Pollution control devices supplied as std.	Particulate	Several	Multicyclone & baghouse	Baghouse	Baghouse	Cyclones & baghouse	Baghouse	Multi-cyclone & baghouse	Multi-cyclone & baghouse
Expected uncontrolled emissions:									
Particulates	1.25 gr/DSCF	90% Ash	1-3 gr/SCF	?	-	100-3000 lb/hr	Variable	<0.01%	?
Nitrogen oxides	0.18 lb/MBtu	Low	100 ppm	?	-	0-22 lb/hr	''	130 ppm	?
Other measured pollutants (Cl)	100 ppm HCl	-	None	?	-	1.2 lb/hr SO_2	''	-	?
Opacity	0.35 lb/MBtu S ?	10-20%	<10%	?	-	70-90	''	#1 (Ringelman	?
Expected controlled emissions:									
Particulates	As required	0.03 gr/DSCF	As required	Local spec.	-	2-252 lb/hr	Variable	0.01%	?
Nitrogen oxides	0.18 lb/MBtu	Very low	100 ppm	''	-	0-22 lb/hr	''	130 ppm	?
Other measured pollutants (Cl)	Suppressed	Very low	None	''	-	0-1.2 lb/hr SO_2	''	-	?
Opacity	?	10%	<10%	''	-	10%	''	#1 (Ringelman)	?
Ash water solids contents	None	25-50 ppm	None	None	-	None	Variable	None	None
Other pollutants in the ash water	None	None	None	None	-	None	Variable	None	None
Pollution control devices for special needs	As required	None	None	—	—	None	None	None	Scrubber

Table D7

Fluidized Bed Combustion Units: Operation

Item	Combustion Power	Dorr-Oliver	Energy Prod.	Fluidyne	GA Tech	Power Recovery	Stone Johnston	TPI	York-Shipley
No. personnel/shift:									
Operators	3	1	1	2	-	1	Variable	1	1
Mechanics	-	On call	On call	1/3	-	1/3	''	0	0
Laborers	-	Part-time	On call	0	-	1	''	0	0
Designed operating schedule (no. shifts/no. days/week)	As required	3/7	3/7	3/7	-	3/7	''	3/7	3/7

APPENDIX E:

TECHNOLOGY COMPARISON

Table E1

Summary of Technologies: General Characteristics

Item	Starved-Air	Rotary Kiln	Grate	FBC
Type of units	Starved-air	Rotary kiln	Grate	FBC
No. units sold/(yr)	5-15	3-10	8	3
Percent industrial vs. municipal	94	100	85	97
Company contracts to operate units?	Avail.	Avail.	Avail.	Avail.
No. in service now	1-2000	1-20	18-1455	34
Expected life of unit (yr)	10-15	10-30/20	20-40	20
Avg. availability (%) (i.e., not down for maintenance, repair)	90	88	90-95	90
Size range per unit (TPD in 3 shifts)	2-100	2-320	1-1250	10-400
Steam generation range (lb/hr)	1K-50K	720-72K	5.6K-250K	2.5K-250K
Expected thermal efficiency (%)	40-70/58	50-75/70	30-70/60	60-85/74
Required fans provided as std?	Yes	Yes	Yes	Yes
Method of preheating combustion air	Available	Preheated	Preheated	Available
Type of waste fuel*	MSW & ind.	MSW & ind.	MSW & ind.	Ind. & RDF

*MSW = municipal solid waste; ind. = industrial; RDF = refuse-derived fuel.

Table E2

Summary of Technologies: Feed System

Item	Starved-Air	Rotary Kiln	Grate	FBC
Recommended waste retrieval system	Front loader	Varies	Varies	Front loader
Type of preprocessing required (if any)	Remove bulky waste	None	Varies	Shred & class
Type of feeding*	Both	Continuous	Continuous	Continuous
Type of feed system**	Ram	Varies	Ram	Pneu. or screw
Expected feed system outage frequency (%)	1-5	?	1-5	2-5
Max. allowable moisture content (%)	25-70/40	50	30-60	30-60/50
Max. allowable ash content (%)	15	No limit	25-40	10-50/30
Max. allowable glass content (%)	10	No limit	15-30	2-20
Max. allowable metal content (%)	?	No limit	8-30	5-10
Feed system special maintenance***	Lubricate	None	None	None
Amount of supplemental fuel	Variable	Variable	Startup only	None

*Continuous or batch.
**Pneu. = pneumatic.
***Air Lance, High-Temperature Lubrication, etc.

Table E3

Summary of Technologies: Combustion Zone and Boiler

Item	Starved-Air	Rotary Kiln	Grate	FBC
Type of combustion grate*	Internal ram	Rotary	Moving grate	FB
Method of indroducing underfire air	Ports	None	Grate	Nozzles
Design heat release rate	?	?	Varies	Varies
Carbon burnup (%)	95	93-98	95-98	98
Primary combustion zone temp. (^{o}F)	1000-2000/14	1400-2900	1600-2200/18	1200-1800/15
Method of maintaining temp.	Air & feed	Air & feed	Air	Air & feed
Secondary combustion zone temp. (^{o}F)	1500-2200/18	1600-2800	1700-2000	1400-2000/16
Expected combustion-related outage frequency (%)	1-5	0-5	None	1-5
Type of retractory	Cast. & brick	Varies	Varies	Brick & cast.
Expected life of retractory (yr)	5-15	1-5	10-20	5-30/11
Type of boiler*	Both	Both	--	Both
Heat transfer rate	?	?	--	?
Soot cleaning method	Man. or blower	Blowers	--	Blowers
Steam temp. range (°F)	Sat. - 600	Sat. - 750	--	400-950
Steam pressure range (psig)	11-600	0-800	--	5-900
Feedwater consumed (gal/ton) (full condensate return)	?	?	--	?
Type/frequency of blowdown** (manual vs auto.)	Either	?	--	?
Expected boiler outage frequency (%)	1-2	0-5	--	1-5

*Inclined, Rotary, FB, etc.
**Firetube or watertube.

Table E4

Summary of Technologies: Ash System

Item	Starved-Air	Rotary Kiln	Grate	FBC
Ratio bottom ash:fly ash	?	?	?	1:3
Type of bottom ash removal system	Ram & conv.	?	Varies	Varies
Method of sealing ash hopper draft*	Both	Both	Both	Mechanical
Expected ash system outage frequency (%)	1-5	1-5	?	1-5
Type of bottom ash cooling	Quench or spray	Quench or spray	Quench or spray	Dry & variable
Ash waste-water produced (if applicable)	0	Varies	?	0

*Water, mechanical, etc.

Table E5

Summary of Technologies: Controls

Item	Starved-Air	Rotary-Kiln	Grate	FBC
Control system*	Auto.	Auto.	Auto. or semi	Auto.
Response to steam output	Yes	No	Yes	Yes
Method of Controlling Steam Output	Bypass	Varies	Feed/bypass	Firing rate
Origin of firing rate control signal**	Temp.	Temp.	Temp.	Temp. & O_2
Type and location of CO or O_2 monitors (if any)	None	None	Varies	Varies
Method of controlling fans***	Dampers	Dampers	Dampers	Dampers
Turndown ratio of unit	2-10:1	2-4:1	3.5:1	2-3:1
No. operators required	1-2	1-2	1	1
Expected control outage frequency (%)	1	0-2	5	1-5

*Auto. = automatic; semi. = semiautomatic.
**CO, O_2, temperature.
***Damping, venting, speed, etc.

Table E6
Summary of Technologies: Environmental Aspects

Item	Starved-Air	Rotary Kiln	Grate	FBC
Pollution control devices supplies as std.	None	Baghouse, ESP scrubber	Baghouse, ESP scrubber, etc.	Baghouse & multicyclones
Expected uncontrolled emissions:				
Particulates	0.08-0.13 gr/DSCF	0.03-0.5 gr/DSCF	0.41-1.1 gr/DSCF	1-3 gr/DSCF
Nitrogen oxides (ppm)	?	?	<35	100-130
Other measured pollutants (Cl)	?	?	Varies	?
Opacity (%)	?	?	20	10-20
Expected controlled emissions:				
Particulates	0.08-0.13 gr/DSCF	0.005-0.03 gr/DSCF	0.01-0.05 gr/DSCF	0.03 gr/DSCF
Nitrogen oxides (ppm)	?	?	<35	100-300
Other measured pollutants (Cl)	?	?	Varies	?
Opacity (%)	?	?	0-3	10
Ash water solids content	NA	?	<50%	NA
Other pollutants in the ash water	0	?	?	0
Pollution control devices for special needs	Scrubber	Yes	Scrubber	None

Table E7

Summary of Technologies: Operation

Item	Starved-Air	Rotary Kiln	Grate	FBC
No. personnel/shift required:				
Operators	1-2	1-2	1	1
Mechanics	0-1	1	1	0
Laborers	0-2	1	0	1
Designed operating schedule (no. shifts/no. days/week)	3/7	3/7	3/7	3/7

APPENDIX F:

MANUFACTURERS STUDIED

Starved-Air Units

Atlas Incinerator, Inc.
Suite 102
277 Coon Rapids Blvd.
Minneapolis, MN 55433
(612) 784-6701

Brulé, Inc.
13922 S. Western Ave.
Blue Island, IL 60406
(312) 388-7900
POC:* Mr. James Moore

Burn-Zol
PO Box 8809
Stockton, CA 95208
(209) 931-1297
POC: Mr. Edward Abendschein

Clear Air, Inc.
811 102nd St.
Naples, FL 33963
(813) 598-9595
POC: Mr. Scott Taylor

Cleaver Brooks (Kelley)
6720 N. Teutonia Ave.
Milwaukee, WI 53209
(414) 962-0100
POC: Mr. Kenneth Schloerke

Comtro
PO Box 70220
Tulsa, OK 74170
(918) 747-1371
POC: Mr. Peter Berry

Consumat Systems
8643 Hinman
Houston, TX 77061
(713) 641-1122
POC: Mr. Ronald Lirette

Ecolaire Combustion Products
PO Box 240707
Charlotte, NC 28224
(704) 588-1620

Simonds Manufacturing Co.
PO Box 1443
Auburndale, FL 33823
(813) 967-8566
POC: Mr. Bill Collins

Stock Equipment Co.
16776 Bernardo Center Dr.
San Diego, CA 92128
(619) 485-9864
POC: Mr. Jerry Mills

Therm-Tec
PO Box 1105
Tualatin, OR 97062
(503) 692-1490
POC: Mr. Dean Robbins

UIP Engineered Products Corp.
145 North Swift Rd.
Addison, IL 60101
(312) 629-8400
POC: Mr. Malcolm Browning

U.S. Smelting Furnace Co.
PO Box 446
Belleville, IL 62222
(618) 233-0129
POC: Mr. Keith Cutler

Washburn & Granger
PO Box 304
Paterson, NJ 07544
(201) 278-1965

*POC = point of contact.

Rotary Kiln Units

C-E Raymond
200 W. Monroe
Chicago, IL 60606
(312) 236-4044
POC: Mr. W.L. Kephart

Giery/Peabody Gordon-Piatt
PO Box 650
Winfield, KA 67156
(316) 221-4770
POC: Mr. Kenneth Puckett

Industrionics
489 Sullivan Ave.
South Windsor, CT 06074
(203) 289-1551

O'Connor Corp.
100 Kalmus Dr.
Costa Mesa, CA 92626
(714) 979-9691
POC: Mr. J. Bruce Frenzinger

Thermall, Inc.
PO Box 1776-T
Peapack, NJ 07977
(201) 234-1776
POC: Mr. Mitchel Gorski

Trofe Incineration
Pike Rd.
Laurel, NJ 08054
(609) 235-3030
POC: Mr. Henry Stein

Excess-Air Grate Units

Basic Environmental
21 W. 161 Hill Ave.
Glen Ellyn, IL 60137
(312) 469-5340
POC: Mr. John Basic

Clear Air, Inc.
811 102nd St.
Naples, FL 33963
(813) 598-9595
POC: Mr. Scott Taylor

Detroit Stoker
PO Box 732
Monroe, MI 48161
(313) 241-9500

Morse Boulger, Inc.
PO Box 825
Bensalem, PA 19020
(215) 638-2700

Olivine Corp.
1015 Hilton
Bellingham, WA 98225
(206) 733-3332
POC: Mr. Corky Smith, Sr.

Fluidized Bed Combustion Units

Combustion Power Co.
1346 Willow Rd.
Menlo Park, CA 94025
(415) 324-4744
POC: Mr. John Guillory

Dedert Corp.
Thermal Processes Div.
20000 Governors Dr.
Olympia Fields, IL 60461
(312) 747-7000
POC: Mr. John Ruhl

Dorr Oliver
79 Havemeyer Lane
Stamford, CT 06904
(203) 358-3834
POC: Mr. Richard Giderti

Fluidyne Engineering
5900 Ohlson Memorial Hwy.
Minneapolis, MN 55422
(612) 544-2721
POC: Mr. H. Hanson

Johnston Boiler Co.
300 Pine St.
Ferrysberg, MI 49409
(616) 842-5050
POC: Mr. John Wallish

York-Shipley
PO Box 349
York, PA 17405
(717) 755-1081
POC: Mr. M.E. Gilligan

Energy Products of Idaho
3805 Industrial Ave. South
Coeur D'Alene, ID 83814
(208) 765-1611
POC: Mr. Michael Oswald

GA Technologies, Inc.
PO Box 85608
San Diego, CA 92138
(619) 455-3646
POC: Mr. Gregory Gushaw

Power Recovery Systems, Inc.
181 Rindge Ave. Extension
Cambridge, MA 02140
(617) 576-1900
POC: Dr. Robert S. Davis

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